POCKET NOTEBOOK

Pocket Orthopaedic Surgery

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Wolters Kluwer

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Pocket

ORTHOPAEDIC SURGERY

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DEDICATION

"For the secret of the care of the patient is in caring for the patient."

DR. FRANCIS W. PEABODY

For all the healers, physicians and surgeons, who taught me that we are healers and physicians before we are technicians, that although knowledge, our dedication to improve it, and to cultivate better judgment are important, so is our **mindfulness, presence, patience, kindness, empathy, and fearlessness** whenever we practice our profession and art.

For my fellowship mentors at Harvard University Drs. Scott Martin, fellowship director, Larry Higgins, Chief, Sports Medicine & BWH Harvard Shoulder Service; Tom Minas, Director Cartilage repair center; Andreas Gomoll; all the mentors and surgeons at Northwestern University; parents Nassif and Nadia; brothers Jawad, Fares, Adnan, Hossam, Rida, and Mohannad; clinical staff including Ryan Hilton, Patricia Agnese, Tari Rowe, Kay Yoshioka, Henrene Ito, Jaimy Brinkman, Ditas Krietemeyer, James Krietemeyer; and finally to all my patients, many thanks and gratitude for your trust; and I hope to continue to serve you the best I can.

JAY BOUGHANEM, MD

"Live as if you were to die tomorrow. Learn as if you were to live forever."

MAHATMA GANDHI

To my mentor and grandfather Pravinkant Dalal (Dada) and my grandmother Bharati Dalal (Dadi); a man whose knowledge surpassed his time and a woman whose familial devotion is the ideal. For my parents, who personify the meaning of unconditional love. For my wife and three sons who are my purest and most wonderful joys in life. Finally, for the master surgeons who taught me the art and the science that is Orthopaedic surgery.

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PREFACE

This book is written with the orthopedic surgery resident, intern, subintern, junior attending, medical student in mind. The goal is not to provide an overarching comprehensive resource to cover all of orthopedic pathology but rather to serve as a concise point of reference to review the important aspects of common orthopedic surgery pathologies for the orthopedist in training or recently out of training.

As we were progressing through residency, we envisioned a great need for a resource like this. For example, an orthopedic resident spending a day in clinic may see 40 or more patients on a given day. Many of the pathologies will be new or relatively new. This book is meant to provide the most important, highly relevant facts regarding the history findings, physical exam findings, pertinent radiographic and advanced imaging findings, as well as literature-supported conservative and operative management options for each common pathology encountered. In addition, it will provide all the landmark articles and highly relevant literature available to justify the diagnosis and management. In the citations or reference sections of this book, we mean to have all the classic and recent relevant literature that should serve as both a reference for further reading on one hand, and a resource for OITE and Boards review on the other. Likewise, an orthopedic resident spending the day in the operating room may use this book as a guide to review the most high-yield information regarding the orthopedic procedure at hand starting with instruments needed, positioning, approach, surgical technique, and postoperative management for the most common orthopedic procedures encountered.

The key idea is to have within the covers of this compact pocket-sized book concise, relevant, to the point, high-yield, and most pertinent information regarding the most common pathologies encountered in the field of orthopedic surgery. The authors of chapters within this book were specifically chosen because of their subspecialty knowledge, ability to synthesize information in a concise fashion, and contemporary training. As we develop our core knowledge in orthopedic surgery during training, it is indispensable to have a foundation and a framework to organize new clinical information around. This framework does not need to be all inclusive, but it does need to be highly relevant, well organized, and written in a "to the point" and "here is what you really need to know" fashion. This is precisely the purpose of this book.

Providing the classic literature as well the recent and relevant articles makes this an excellent resource for further reading before or after clinic or surgery.

CO-EDITORS AND CO-AUTHORS
JAY BOUGHANEM, MD
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CONTENTS

EVALUATION OF THE TRAUMATIZED PATIENT

JEFFREY S. EARHART

Epidemiology (United States)

- According to the most recently available CDC data (2010), accidents are the fifth leading cause of death in all age groups in the United States at a rate of 38.2 per 100,000 people.
- Thirty percent of accidental deaths were due to motor vehicle collisions.
- Accidents are the most common cause of death in patients <45 yrs and are the third most common cause between 45 and 65 yrs.

Clinical History and Presentation

- *ATLS*
  - Protocol for rapid evaluation and treatment of traumatized patients includes a primary survey and resuscitation, secondary survey, and appropriate definitive care.
  - In the United States, protocols are run under the direction of the emergency physician and/or general surgery traumatologist.
  - Any change in patient condition should prompt an immediate return to the ABCs before continuing through the phases of management.
- *Primary survey*
  - ABCs and ongoing resuscitation efforts
    - **Airway**—Goals are to evaluate, establish, and maintain a patent

airway while protecting the cervical spine.

  - Physician-assisted measures include jaw-lift, oral/nasal airways, endotracheal/nasotracheal intubation, and surgical airways (cricothyroidotomy).
  - Intubation controls the airway in unconscious patients or those with obstruction from neck/facial trauma as well as in combative or obtunded patients.
  - Cervical spine precautions are continued until definitive clearance can be obtained.
- **Breathing—**Goals are to assess for and provide adequate oxygenation and ventilation, whether patient driven or mechanically assisted.
  - Monitored continuously by transcutaneous oxygen saturation readings and intermittently with arterial blood gas levels.
  - Any decompensation first requires reassessment of the airway followed by timely evaluation for underlying etiology. In the traumatized patient this may include hemopneumothorax, tension pneumothorax, flail chest, hemopericardium, pulmonary contusion, ongoing exsanguination, and CNS decompensation.
  - Lifesaving procedures are performed if needed (intubation, needle thoracostomy, chest tube, pericardiocentesis, thoracotomy).
- **Circulation—**Goals are to detect signs of shock and to control sources of bleeding.
  - Patients are treated with 2 L of warmed crystalloid and physiologic response is noted.
  - Unstable pelvic injuries should be stabilized with a pelvic binder or a clamped bed sheet centered on the greater trochanters.
  - In the absence of significant chest or abdominal sources of hemorrhage, failure of blood pressure to respond to fluid and external pelvic stabilization should prompt further intervention (angiogram with selective or nonselective embolization, or preperitoneal pelvic packing).

- Sterile dressings and direct pressure on bleeding wounds is preferred over the blind use of clamps.
- Potentially significant blood loss from orthopedic injury: pelvis (>8 units), closed femur (2–3 units), closed tibia (1–2 units). Estimates increase for open injuries.
- If blood products are required, start with warm O-negative packed red cells.

- **Access**
  - Minimum of 2 large-bore antecubital IVs or central venous access.
  - Often established concurrently with the ABCs but should be delayed until circulation assessment if obtaining access would interfere with securing the airway or proper oxygenation/ventilation.
- **Disability/CNS**
  - Goals are to assess general neurologic status including assignment of GCS score from 3–15: Eye movement (4), verbal response (5), motor response (6), $3 =$ dead, $<8 =$ severe brain injury (requires intubation), $9–12 =$ moderate brain injury, $>13 =$ mild injury.
  - Obvious head injury, signs of elevated intracranial pressure, or changes in mental status may direct further workup.
  - Mean arterial pressure should be kept above 80 mm Hg after head trauma to avoid secondary injury.
- **Exposure**
  - Goal is expeditious evaluation of all body regions for signs of injury including the axillae, pelvis, back/spine, and perineum.
  - A pelvic exam for stability in the axial and sagittal planes should be performed only once to avoid clot dislodgement in the presence of an unstable injury.
  - Protect the spine by using log roll technique.
  - Perineal assessment includes inspection of urethra, vagina, and rectum for blood or other signs of injury.

- Apply sterile dressings to any open wounds and splint/immobilize any obvious fractures.
- The bladder should be catheterized unless signs of injury are present (blood at urethral meatus, high-riding prostate).
- When this is completed, cover the patient with warm blankets to prevent hypothermia

- *Resuscitation*
  - Goals are to maintain tissue perfusion and meet the metabolic demands of vital organs.
  - If blood pressure and heart rate response to the initial fluid challenge is transient or absent, provide blood products and crystalloid while continuing to identify and manage all sources of hemorrhage.
  - Severe hemorrhage may require massive transfusion of packed red cells (O-negative until ABO typing can be completed), fresh frozen plasma, and platelets given in 1:1:1 ratio.
  - Fibrinogen levels should be monitored and replaced with cryoprecipitate.
    - *Unreliable* measures of completed resuscitation (due to compensated shock): blood pressure, urinary output, and hemoglobin/hematocrit.
    - *Reliable* measures of completed resuscitation: normalized base deficit (> -3.0) and serum lactate (< 2.5) with correction of coagulopathies and hypothermia.

Physical Exam

- *Secondary survey*
  - Perform an AMPLE history (allergies, medications, past medical history, last meal, events surrounding injury).
  - Complete the physical exam assessing for laceration, fracture, neurologic impairment, and blunt soft tissue injury.
  - Thorough vascular exam should be completed with further angiographic workup initiated as needed.

- Examine abdomen for signs of blunt injury and conduct FAST (Focused Abdominal Sonography for Trauma) exam or CT of the chest, abdomen, and pelvis to assess for sources of bleeding.
  - Peritoneal lavage is now used infrequently for this assessment.
  - Positive findings or ongoing hemodynamic instability warrant operative exploration.
- If not performed during the primary survey, a rectal and vaginal exam may be performed to assess for blood or laceration.
- If a Foley was not passed previously due to suspicion of bladder or urethral injury, urologic consultation should be requested.
- Finally, all 4 extremities should be assessed for fracture, crepitus, swelling, pain, instability, and range of motion.
  - Compartment syndrome should be suspected in crush injury and checked clinically or with invasive pressure monitoring in the unconscious or uncooperative patient.

- *Orthopedic emergencies*
  - Open fractures, dislocations (hip and knee in particular), compartment syndrome, cauda equina syndrome, dysvascular limb, or neurologic injury.
  - Problem fractures (femoral neck) are urgent but not emergent when no joint dislocation is present.
- *Orthopedic priorities*
  - Spinal injury should be diagnosed and managed expeditiously to prevent neurologic deterioration.
  - Dislocations must be reduced and stabilized with splints, fixators, or traction.
  - Fasciotomies are needed in compartment syndrome and following revascularization of extremities.
  - Open wounds and fractures require immediate and appropriate administration of antibiotics and tetanus prophylaxis followed by thorough debridement and irrigation.
  - Unstable pelvic injuries should be initially treated with binders or sheets, followed by external or definitive fixation depending on

patient condition and concomitant injuries.

- Femur fractures should be assessed for ipsilateral femoral neck fractures (up to 9%) and either fixed, spanned, or placed in traction depending on patient resuscitation and condition.
- Lower priority fractures (particularly upper extremity long bones) should be closed reduced and splinted.

IMAGING

- *Trauma series*
  - AP chest—Pneumothorax, cardiac silhouette, tracheal deviation, fracture
  - AP pelvis—Fracture, ligamentous injury, fifth transverse process fracture, ± hip and femoral neck
  - Lateral cervical spine—Must include C7–T1 junction. No longer ATLS standard and largely replaced by CT.
  - *CT chest/abdomen/pelvis:* Has replaced FAST exam and diagnostic peritoneal lavage at many institutions for assessment of injury to viscera and other sources of hemorrhage.

CLASSIFICATIONS/DEFINITIONS

- *Injury severity score (ISS)*
  - Anatomic scoring system obtained by the sum of the square of the 3 highest Abbreviated Injury Scale (AIS) scores, allowing for 1 maximal injury per body region (head/neck, face, chest, abdomen, extremities, and external/soft tissue).
  - Any regional AIS score of 6 is an automatic ISS of 75. Polytrauma patients are defined by ISS >18.
- *Hemorrhage* (Table 1)
- *Shock*
  - **Hypovolemic:** Circulating volume insufficient for vital organ metabolic demands.

- Treat with volume support, blood products, and occasionally inotropic agents.
- **Cardiogenic:** Insufficient cardiac output (tamponade, arrhythmia, infarction, contusion).
  - *Beck triad:* A sign of cardiac tamponade requiring pericardiocentesis (distended neck veins, muffled heart sounds, hypotension).
- **Neurogenic:** Systemic vasodilation characterized by hypotension with bradycardia from loss of sympathetic outflow in cervical or high thoracic cord injury.
  - Treat with volume support and vasoconstrictors.
- **Spinal:** Metabolic derangement after cord injury with flaccid paralysis, loss of sensation, and loss of reflexes below the level of injury.
  - Return of bulbocavernosus reflex signals end of spinal shock and allows for determination of complete versus incomplete cord injury.
- **Septic:** Systemic vasodilation in response to severe blood-borne infection, typically late sequela in trauma.

Table 1.1 Hemorrhage Classification

Class	Blood Volume (%)	Blood Loss (cc)	Vitals Change	Urine Output	Treatment
I	15	<750	NA	No change	Crystalloid
II	15–30%	750–1,500	± Tachycardia	20–30 cc/hr	Crystalloid
III	30–40%	2,000	Hypotension	10–20 cc/hr	Blood
IV	>40%	>2,000	Sig hypotension	Min	Blood

Pathophysiology

- Details of physiologic mechanisms remain poorly understood.
  - Local tissue injury leads to normal inflammatory cascade for containment and early immune protection.
  - Severe blunt injury leads to an exaggerated response, increased production of cytokines (IL-1, IL-6, IL-8, IL-10, INF, TNF-α), and

systemic neutrophil activation and extravasation into tissues.

- This causes remote injury via PMN release of proteolytic enzymes, reactive oxygen species, and vasoactive agents; endothelium damage with leakage of fluids into tissues; and ultimately failure of multiple organ systems.
- Primary definitive surgical interventions during the early posttraumatic inflammatory state are felt to act as a "second hit" leading to the exaggerated systemic response. Monitoring of inflammatory state with IL-6 levels remains promising but impractical for clinical practice.

Surgical Decision Making

- *Early total care (ETC) versus damage control orthopedics (DCO)*
  - *ETC*
    - Evolving debate regarding timing of definitive fixation of major extremity fractures with goal of limiting systemic complications including ARDS, MSOF, and death.
    - Literature primarily focuses on fixation of femur fractures in polytraumatized patients.
    - Historically, delayed treatment was preferred to avoid pulmonary complications of fixation. Early fixation became popular in the 1980s after studies showed decreased incidence of ARDS but timing was poorly defined, leading to poor outcomes in some instances.
  - *DCO* is a U.S. Navy tactic adopted by general trauma surgeons for hemorrhage control and later by orthopedic traumatologists for rapid stabilization of fractures using external fixators as part of resuscitation and prevention of hyperinflammatory states.
    - Current practice advocates use of DCO techniques in borderline or unstable patients with correction of physiologic parameters prior to definitive surgery: Normalized serum lactate and base deficit, resolution of hypothermia, and platelets $>100{,}000$ with normalized PT/PTT/INR.
- *Patient status:* Based on 4 pathologic cascades of polytrauma (shock,

hypothermia, coagulopathy, and soft tissue injury)

- **Stable:** Patient is resuscitated and cleared for ETC
- **Borderline:** Condition is uncertain with episodic cardiovascular instability and hypoxemia. Response to ongoing resuscitation and intraoperative monitoring dictates ETC versus DCO.
- **Unstable:** Ongoing cardiovascular instability and hypotension. Generally receive only lifesaving interventions and DCO.
- **In extremis:** Patient has acutely life-threatening injuries requiring aggressive resuscitation and lifesaving measures before even damage control measures can be undertaken.

Mortality

- *Early phase:* Death on-scene (seconds to minutes)
  - Severe neurologic injury, rapid exsanguination
  - Limited intervention opportunity
- *Second phase:* Death early in hospitalization (hours to days)
  - Hypoxia, hemorrhage, neurologic injury
  - Multiple pelvic/extremity injuries, sub/epidural hematomas, hemopneumothorax, solid organ injury
  - Improved by prehospital care, ATLS and lifesaving procedures, resuscitation/transfusion protocols, ICU care
- *Third phase:* Delayed inhospital mortality (days to weeks)
  - Head injury, SIRS, ARDS, sepsis, multisystem organ failure
  - Largest opportunity for future improvement in care

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CLAVICLE FRACTURES

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Clavicle Anatomy

The clavicle is an S-shaped bone that acts as a strut between the upper extremity and axial skeleton. It is the first bone to ossify, and the proximal physis is the last ossification center in the body to close. The clavicle has numerous important muscular and ligamentous attachments including the sternocleidomastoid muscle proximally as well as the trapezius and anterior deltoid muscles distally. The coracoclavicular (CC) ligament is composed of the conoid (medial) and trapezoid (lateral) ligaments and acts to prevent superior displacement of the distal clavicle.

Clinical History/Presentation

- Clavicle fractures are common orthopedic injuries and account for 2.6–5% of all fractures.
- Epidemiologically, clavicle fractures occur more than twice as often in men than women.
- The most common mechanism of injury is a fall directly onto the ipsilateral shoulder resulting in an axial loading force to the clavicle.
- Less commonly, clavicle fractures occur as a result of a direct strike or a fall onto an outstretched hand.
  - Midshaft fractures account for 69–82% of all clavicle fractures.
  - The distal clavicle is the next most common fracture location (~20%) followed by the relatively rare proximal clavicle fracture.

Physical Exam

- Characteristic physical exam findings include a noticeable deformity, swelling, ecchymosis, and tenderness to palpation at the fracture site.
- A thorough neurovascular exam of the ipsilateral extremity is of paramount importance.
- Although rare, damage to the underlying subclavian vessels or brachial plexus has been reported.
- A high index of suspicion should also exist for other concomitant injuries such as sternoclavicular (SC) or acromioclavicular (AC) joint dislocations, scapular fractures, a pneumothorax or hemothorax, and rib fractures.

Imaging

- Radiographs are sufficient to diagnose most clavicle fractures.
- A standard anteroposterior (AP) view combined with a 30-degree cephalic tilt radiograph is all that is typically necessary for visualizing midshaft clavicle fractures.
- An additional radiographic view to better assess the AC joint is known as a Zanca view and is performed by tilting the beam in a 15-degree cephalad direction.
- Computed tomography (CT) is commonly reserved for specific cases such as proximal clavicle fractures that may involve the SC joint, fracture nonunions, or fractures with a significant degree of comminution.

Classification

- Multiple classification systems exist; one of the most commonly utilized and relatively simplistic is the Allman classification system.
  - Fractures are divided among 3 primary types based on the anatomic location (1, midshaft; 2, distal; 3, proximal).

- Further subcategorization occurs depending on specific fracture characteristics.
- *Allman Classification system*
  - 1: Middle third fractures
  - 2.1: Minimally displaced distal clavicle fractures
  - 2.2A: Displaced distal clavicle fracture with the CC ligament attached to distal fracture fragment
  - 2.2B: Conoid ligament torn with the remaining trapezoid ligament attached to the distal fracture fragment
  - 2.3: Intra-articular fracture of the AC joint; the CC ligament is not affected
  - 3.1: Minimally displaced proximal clavicle fracture
  - 3.2: Displaced fracture
  - 3.3: Intra-articular fracture of the SC joint
  - 3.4: Epiphyseal separation
  - 3.5: Comminuted proximal clavicle fracture

Nonoperative Management

- Acute immobilization of the ipsilateral upper extremity is the mainstay treatment for clavicle fractures.
  - Immobilization typically lasts 4–6 wks in duration and can be accomplished by numerous methods.
  - The figure-of-8 brace and the sling are two of the most commonly used devices.
  - A prospective randomized study comparing these two methods demonstrated that they both resulted in similar rates of fracture union and alignment; however, only 7% of sling patients compared to 26% of figure-of-8 brace patients reported dissatisfaction with their method of immobilization.
  - During the period of immobilization emphasis should be placed on daily range-of-motion activities for the elbow, wrist, and fingers.

Operative Indications

- The indications for operative fixation of midshaft clavicle fractures are an area of current interest as well as controversy in the orthopedic field.
- Open or impending open fractures as well as fractures associated with a vascular or neurologic injury demand surgical intervention.
- Relative indications for operative fixation include
  - trauma patients with multiple fractures.
  - painful fracture malunion or nonunion.
  - fractures with >15–20 mm of shortening or those that are completely displaced.
- Recent studies have shown that nonoperatively treated midshaft clavicle fractures in patients with >20 mm of shortening have greater dissatisfaction, decreased shoulder abduction strength, and endurance as well as a higher rate of nonunion and malunion when compared to an operatively treated cohort.

Surgical Technique

- Operative stabilization of clavicle fractures is accomplished primarily with plates and, to a lesser degree, intramedullary (IM) devices.
- *Plating* results in greater rotational control and provides the ability to compress the fracture fragments; however, it requires greater fracture site soft tissue disruption.
  - The most commonly used plates:
    - 3.5-mm limited contact dynamic compression plate (LC-DCP)
    - 3.5-mm locking compression plate (LCP) or a precontoured plate
  - These plates can be placed in an anterosuperior, anterior, or anteroinferior position.
    - The *anterosuperior* side of the clavicle is considered the tension side, therefore, providing the position for the most biomechanically stable construct.

        - However, *anteroinferior* plating can provide a more cosmetically pleasing result, and drilling from this position places the underlying neurovascular structures at less risk of iatrogenic damage.
    - Patients are positioned either supine on a radiolucent table or in a beach chair position.
        - A bump is placed underneath the scapula and the entire ipsilateral extremity is prepped to allow for retraction if needed.
        - The ipsilateral iliac crest should also be prepped and draped to allow for obtaining autograft bone in cases with significant comminution or bone loss.
        - A transverse skin incision slightly inferior to the clavicle is made, and the underlying subcutaneous fat and musculofascial layer are incised until the fracture is identified.
        - The vertically oriented branches of the supraclavicular nerve should be identified and protected during the approach.
        - The fracture is reduced, and an appropriately contoured plate is applied and secured with 3 bicortical screws proximally and distally (if space allows) to the fracture.
        - The incision is closed and the arm is immobilized in a sling.

Postoperative Rehabilitation and Expectations

- Postoperatively the extremity is placed in a sling for comfort.
- In cases of stable fixation patients are allowed to immediately begin passive range-of-motion exercises of the ipsilateral shoulder.
- Functional activities are typically allowed after 2 wks or when tolerated by the patient.
- Overhead active exercises and strengthening are commonly initiated at 6 wks.
- Return to sporting activity is typically accomplished by 3 mos postoperatively.

Complications

- Common surgical complications include fracture nonunion, malunion, infection, and hardware irritation or migration.
- Infection after plating has been shown to occur in 5% of cases.
- Case series have found that a large portion of operatively stabilized fractures require hardware removal due to plate prominence and irritation.

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GLENOHUMERAL DISLOCATIONS AND PROXIMAL HUMERUS FRACTURES

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Anatomy/Pathoanatomy

The glenohumeral joint consists of the proximal humerus, glenoid, associated capsular attachments, and the rotator cuff. Glenohumeral stability is provided by the rotator cuff and ligamentous structures. The supraspinatus, infraspinatus, teres minor, and subscapularis tendons confer dynamic stability. The superior glenohumeral ligament provides restraint to inferior translation of the humerus. The middle glenohumeral ligament provides restraint to anterior translation when the arm is in the midrange of abduction. The anterior and posterior bands of the inferior glenohumeral ligament provide restraint to anterior and posterior translation, respectively, when the arm is fully abducted. The glenoid labrum provides additional restraint to humeral translation.

The proximal humerus articular surface is retroverted 30–40 degrees relative to the epicondylar axis of the humerus with a neck–shaft angle of approximately 130 degrees. The lesser tuberosity is the insertion of the subscapularis and the greater tuberosity is the insertion for the supraspinatus, infraspinatus, and teres minor. The tuberosities are separated by the intertubercular groove through which the long head of the biceps runs.

The blood supply of the proximal humerus is from the anterior and posterior humeral circumflex arteries.

Epidemiology

- The glenohumeral joint is the most commonly dislocated joint in the body.
  - Anterior dislocations are more common than posterior dislocations at a ratio of 9:1.
  - Posterior dislocations are associated with electrical shocks or seizures and are often missed on initial presentation. Inferior dislocations (luxatio erectae) are rare.
- Fractures of the proximal humerus account for approximately 5% of all fractures and occur primarily in elderly women.
  - A fracture of the proximal humerus places patients at increased risk for subsequent hip fractures.

Physical Exam

- Anterior glenohumeral dislocations will result in a "squared-off" appearance of the shoulder, as the normal deltoid contour is lost without the proximal humerus in place.
  - The arm is usually held in slight abduction and external rotation, and the patient will be unable to internally rotate the arm.
  - With a posterior dislocation, the arm will be more adducted, and the patient cannot externally rotate or forward elevate the arm.
- Patients with proximal humerus fractures may have ecchymosis and swelling about the shoulder, and movement of the arm will be painful.
- A thorough neurovascular exam is important, with particular attention to the axillary nerve, which is commonly injured with anterior dislocations.

Imaging

- Standard radiographs of the shoulder including an AP, true AP (Grashey), Y, and axillary views should be obtained.

- The axillary view is of critical importance because it can detect posterior dislocations that may be otherwise missed on the other views.
- If the patient is in too much pain for an axillary view, a Velpeau view may be obtained.
- Other specialty views such as the Stryker notch view to detect Hill–Sachs lesions and the West Point view for glenoid rim fractures may be useful.
- Radiographs of the entire humerus should be obtained, especially if intramedullary fixation is under consideration.

- Additional imaging such as CT is usually not necessary, except if head splitting or other complex fracture patterns are suspected.
- MRI should be obtained in patients over 50 if they have functional deficits at follow-up, as rotator cuff injuries commonly occur during glenohumeral dislocations.

Classification

- Glenohumeral dislocations are described by the direction the humerus is displaced.
- Proximal humerus fractures are classified with the Neer classification.
  - This system divides the humerus into 4 parts: humeral head, greater tuberosity, lesser tuberosity, and the humeral shaft.
  - To be considered a part, each fragment must be displaced >1 cm or angulated >45 degrees.
  - The AO/OTA system is used primarily for research and databases.

Initial Care

- Adequate analgesia is essential for reduction.
  - Intra-articular injection of local anesthetic and conscious sedation have been shown to be equally effective in terms of success of reduction and pain control.

- Many reduction maneuvers have been described.
  - **Traction–countertraction:**
    - An assistant applies countertraction through a sheet placed around the patient's body into the axilla.
    - The physician applies steady, gradual traction with the arm in a semiabducted position.
  - **FARES:**
    - The physician pulls gradual traction in a semiabducted position.
    - He or she then performs small oscillations of the arm in the anterior–posterior plane.
    - The arm is gradually abducted, and must be externally rotated around 90 degrees to clear the acromion, with reduction taking place around 120 degrees of abduction.
  - **Stimson technique:**
    - The patient is prone with the affected arm hanging off the bed.
    - Manual traction or weights are applied to the wrist.
    - The reduction takes place over 15–20 min.
  - **Milch technique:**
    - The physician applies a laterally directed force to the humeral head while the arm is abducted and externally rotated.
    - This is often useful as an adjunct to the traction method.
  - **Hippocratic technique:**
    - The physician applies countertraction, placing a foot against the chest wall.
    - Traction is applied to the arm with gentle internal–external rotation.
  - **Kocher technique:**
    - The humeral head is levered over the glenoid rim.
    - This technique is out of favor due to the risk of fracture.
- Reduction of posterior dislocations usually requires complete sedation.

- In-line traction should be applied while lifting the humeral head into place.
- Lateral traction on the arm may be required.

- After reduction, the patient should be placed into a sling.
  - A swathe may provide patient comfort but should be discontinued after follow-up.

Nonoperative Treatment

- Most glenohumeral dislocations are treated nonoperatively.
  - Patients are generally immobilized in a sling, but the duration and position of immobilization have been controversial.
  - Multiple studies have demonstrated there is no reduction in redislocation with immobilization >1 wk's duration.
  - Cadaver and clinical studies have shown that immobilization in 60 degrees of external rotation will tighten the capsulolabral complex and may prevent redislocation.
  - However, subsequent trials have been unable to redemonstrate this benefit.
- Nondisplaced and minimally displaced proximal humerus fractures are amenable to nonoperative treatment.
  - Patients may use a sling for comfort and begin pendulum exercises immediately, as well as finger, wrist, and elbow motion.
  - Patients should be advised that sleeping upright in a recliner may be more comfortable at first, and that ecchymosis and swelling will track down the arm to their fingers.
  - Patients may begin passive range-of-motion protocols within 2 wks of injury while true active range of motion is usually delayed for 6 wks.
  - Strengthening begins at 12 wks.
- In elderly, low-demand patients, many 3- and 4-part fractures may be considered for nonoperative therapy.
  - Valgus-impacted fractures do particularly well with nonoperative

treatment.

Operative Indications

- Operative treatment of glenohumeral dislocations is generally reserved for patients with associated displaced tuberosity fracture, recurrent instability or first-time dislocators with an unacceptably high risk of redislocation.
- Displaced proximal humerus fractures are considered for surgical intervention.
  - Although patients with low functional demands may do well with nonoperative treatment, most patients with displaced fractures will achieve predictable, good outcomes with operative treatment.
  - Closed reduction and percutaneous pinning (CRPP), ORIF, proximal humeral nailing, hemiarthroplasty, and reverse total shoulder arthroplasty all have roles in the management of these fractures.
  - Isolated greater tuberosity fractures are unique, and considered for operative treatment when they are displaced >5 mm or have significant superior displacement that could result in impingement.
  - As little as 2- or 3-mm displacement may warrant intervention in patients with significant overhead demands.
- Hemiarthroplasty and reverse total shoulder arthroplasty are typically reserved for patients with 4-part fractures with poor bone stock or dislocations.
  - Concern over poor vascularity of comminuted 3 and 4-part fractures is no longer considered to be a contraindication for ORIF.
  - Although osteonecrosis may result if ORIF is attempted, outcomes are not necessarily poor as osteonecrosis is well tolerated in some patients.

Surgical Approaches

- The deltopectoral approach is the workhorse for the shoulder and may be extended into the anterolateral approach to the humerus.
  - It utilizes the interval between the axillary nerve and medial and lateral pectoral nerves.
  - The incision is carried from the coracoid to the biceps insertion along the deltopectoral groove.
  - The cephalic vein may be identified by an overlying fat stripe and lies in the deltopectoral groove.
    - It should be carefully mobilized and retracted medially or laterally.
    - It is advantageous to take it medially but more often will go laterally with less bleeding.
  - Blunt dissection is carried out into the subacromial and subdeltoid spaces.
  - The clavipectoral fascia is divided along the incision.
  - The conjoined tendon can be retracted medially, but careful retractor placement and avoiding overzealous retraction is key.
  - Care must be taken near the inferior aspect of the subscapularis as the anterior circumflex crosses the humerus.
- Alternatively, the anterolateral acromial (deltoid-splitting) approach allows more direct plate placement and may be particularly useful for surgical neck fractures.
  - The incision is off the anterolateral aspect of the acromion.
  - The raphe between the anterior and middle portions of the deltoid is split in line with the deltoid fibers.
  - The axillary nerve will cross perpendicular to the split between 4 and 6 cm from the acromion.
    - The nerve is identified and preserved; the fracture is then reduced and fixed using windows above and below the neurovascular pedicle.

Operative Technique

- Isolated greater tuberosity fractures are amenable to tension band fixation.
  - This is performed with heavy nonabsorbable suture and transosseous tunnels.
  - Alternatively, cancellous screws and washers may be used.
- Closed reduction with percutaneous pin fixation is an alternative to ORIF, especially in patients with good bone stock and simpler fracture patterns.
  - Reduction of the shaft beneath the head usually requires longitudinal traction with a posterolaterally directed force.
  - The shaft and head segments are held with terminally threaded 2.8-mm Shantz pins placed retrograde from lateral and anterior.
  - The lateral pins place the axillary nerve at risk while the anterior pins place the long head of the biceps at risk.
- Internal fixation can be performed through either described approach, with the patient in the beach chair or supine position.
  - The tuberosities should be tagged with nonabsorbable suture to aid in control for reduction as well as ultimate fixation.
  - Provisional reduction is obtained and then maintained with K-wires.
  - The use of locking fixation is standard for the head fragment.
  - Most proximal humerus plates sit just lateral to the bicipital groove and must not sit too superior for risk of subacromial impingement.
  - Intra-articular penetration with proximal screws should be avoided.
    - The tuberosity sutures may be passed through the plate to augment fixation.
    - A “calcar” screw along the neck of the head/shaft junction is important for maintenance of reduction.
- Outcomes after hemiarthroplasty are dependent on successful reduction and healing of the tuberosity fragments.
  - The patient is in the beach chair position and a standard deltopectoral approach is used.

- The tuberosities should be tagged with nonabsorbable suture.
- The articular fragments may be excised.
- The stem should be sized appropriately for cemented or uncemented fixation, depending on the system used.
  - Trialing various humeral heads to aid in restoring humeral height and retroversion are important.
  - The superior aspect of the humeral head should sit 5.6 cm above the superior border of the pectoralis major.
  - After the stem is fixed, the tuberosities should be reduced and held with a system of nonabsorbable suture that travels between tuberosities, from each tuberosity to the shaft, and through the prosthesis.

- Recently, the use of proximal humeral nails for ORIF and reverse shoulder arthroplasty for fracture care are increasing in popularity, but the indications and long-term results are not yet fully understood.

Postoperative Care

- After ORIF, patients may begin passive motion immediately.
  - Generally, they begin with pendulum exercises and progress to a passive protocol by 2 wks.
  - Active-assist exercises begin at 6 wks. Strengthening exercises are delayed until bony union, usually at 12 wks.
- After percutaneous pinning, patients will begin with similar pendulum exercises.
  - Passive range-of-motion exercises are instituted around 3–4 wks, at which time the pins are also removed.
  - Active range of motion begins around 6 wks, with strengthening again delayed until union.
- Hemiarthroplasty patients will follow a similar protocol, although passive range-of-motion exercises may begin immediately.

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HUMERAL SHAFT AND DISTAL HUMERUS FRACTURES

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Anatomy and Pathoanatomy

The humeral diaphysis is tubular proximally and tapers to a triangular shape distally. The intramedullary canal terminates just proximal to the olecranon fossa and coronoid fossa. These are recesses for the olecranon and coronoid processes that allow for a greater flexion–extension arc. The anterior and posterior compartments of the arm are divided by the medial and lateral intermuscular septa. The distal humerus consists of the medial and lateral condyles, medial and lateral epicondyles, and the articular surface consisting of the capitellum and trochlea. The flexor–pronator mass originates from the medial epicondyle while the common extensor origin is on the lateral epicondyle.

The radial nerve courses around the posterior aspect of the arm from proximal-medial to distal-lateral. It lies on the posterior of the humerus approximately 20 cm above the medial epicondyle to 14 cm above the lateral epicondyle. It pierces the lateral intermuscular septum at an average of 10 cm above the lateral epicondyle. The ulnar nerve traverses the elbow immediately posterior to the medial epicondyle in the cubital tunnel.

The blood supply to the humerus is from the nutrient artery of the profunda brachii, which enters the bone posteriorly.

Epidemiology

- Humeral shaft fractures account for 1–5% of all fractures while distal humerus fractures account for 0.5–7% of all fractures.

- Both occur primarily in young men and elderly women.

Physical Exam

- Care of the patient should follow ATLS guidelines.
- Perform a secondary survey looking for other injuries.
- A thorough and accurate neurovascular exam is imperative, especially for the radial nerve.
- The examiner should also assess the skin and soft tissues for open fractures or other injuries that may affect treatment.

Imaging

- Orthogonal views of the humerus with dedicated shoulder and elbow films are standard.
- Oblique views may be useful for distal humerus fractures.
- Traction views of the distal humerus are generally helpful in delineating fracture pattern.
- CT scans help with evaluation of coronal articular fractures.

Classification

- Classification of humeral diaphyseal fractures is primarily descriptive.
- For distal humerus fractures, the AO/OTA classification is useful.
  - In this system:
    - A-type fractures are extra-articular
    - B-type fractures are partial articular (e.g., medial or lateral condyle only, coronal plane fractures)
    - C-type fractures have complete separation of the articular surface from the diaphysis.

- Other classification systems, such as the Jupiter and Milch, are less commonly used.

Initial Care

- Initial care should focus on patient comfort.
- For a humeral shaft fracture, a coaptation splint with a valgus mold will provide stability and correct alignment.
- For a distal humerus fracture, a well-padded posterior-mold splint will provide comfort and stability.

Nonoperative Treatment

- Nonoperative treatment is the mainstay for humeral shaft fractures.
  - The humerus can tolerate significant angulation without apparent cosmetic or functional deficit.
  - Published parameters for nonoperative treatment include < 20 degrees of sagittal angulation, < 30 degrees of varus–valgus angulation, and up to 2–3 cm of shortening.
  - Functional (Sarmiento) bracing is the principal method of nonoperative treatment.
    - The brace is applied about a week after injury and relies on hydrostatic forces for compression.
    - It requires frequent retightening and good hygiene.
    - Flail extremity is a contraindication to functional bracing, and certain fracture patterns, notably proximal third spiral fractures and transverse mid-diaphyseal fractures, are prone to nonunion.
    - Union rates approach 97% in some series.
- Nonoperative treatment of distal humerus fractures is uncommon.
  - This is generally reserved for patients who are medically infirm and would be unable to tolerate surgery, or people with limited functional use of their arm.

- Some non- or minimally displaced extra-articular fractures may be amenable to nonoperative treatment, but maintaining reduction is difficult and prolonged elbow immobilization leads to stiffness.

Operative Indications

- There are a number of relative indications for operative treatment of humeral shaft fractures.
  - These include open fractures, fractures with an associated vascular injury, an associated articular component that requires fixation, failure of nonoperative management, and fractures in polytraumatized patients to permit weight bearing on the arm.
  - Operative treatment for secondary radial nerve palsy after fracture reduction is controversial.
- Distal humerus fractures are generally operative unless they are nondisplaced extra-articular fractures.
  - Absolute indications include open fractures and associated vascular injury.

Surgical Approaches

- Surgical approaches about the humerus are generally limited by nervous anatomy and should be dictated by the location of the fracture.
- The anterolateral approach to the humerus is useful for middle- and proximal-third fractures.
  - It is also useful for associated or contiguous proximal humerus fractures as the approach may be extended into the deltopectoral approach to the shoulder.
  - Distal exposure is limited by the lateral antebrachial cutaneous and radial nerves, and thus the exposure is not useful for distal third fractures.
  - The incision is along the lateral border of the biceps.
  - After medial retraction of the biceps, the brachialis is divided

between the lateral- and middle-thirds.

  - There is no true internervous plane as the brachialis has dual innervation from the musculocutaneous and radial nerves.

- Posterior exposure depends on safe identification of the radial nerve but permits excellent visualization of nearly the entire bone.
  - It is useful for middle- and distal-third fractures, as well as fractures with articular extension to the elbow.
  - Posterior approaches may be triceps-splitting or triceps-reflecting.
    - The triceps split utilizes the raphe between the long and lateral heads of the triceps, then divides the medial head.
      - There is no internervous plane, and attention must be paid to the radial nerve in the spiral groove.
      - This approach permits visualization of the distal 55% of the humerus, but with mobilization of the radial nerve, up to 77% can be visualized.
    - A triceps-reflecting approach can be used to visualize the distal 94% of the humerus without splitting muscle.
    - The posterior brachial cutaneous nerve is followed from the lateral intermuscular septum to the spiral groove where it joins the radial nerve, which is identified and isolated.
      - The triceps is then reflected off the lateral intermuscular septum and retracted medially.
      - The approach is limited proximally by the axillary nerve.
- Medial exposure is possible and often used for open reduction internal fixation (ORIF) when vascular surgeons have used it for repair of a vascular injury.
  - A direct lateral exposure is also possible but much less commonly used.
- Posterior approaches are also the workhorse for distal humerus fractures.
  - However, for distal humerus exposures, identification and protection of the ulnar nerve is paramount.
    - The incision should curve laterally around the point of the

olecranon.

- The triceps split, performed in a similar manner, allows exposure from the posterior articular surface into the diaphysis.
- A paratricipital approach is useful for AO A-type and C1-type fractures.
  - This involves elevating the triceps off the medial and lateral intermuscular septa, watching for the radial and ulnar nerves piercing the septa proximally.
  - The triceps can be elevated off the posterior humerus and the capsule can be incised to allow intra-articular visualization.
- In fractures with a significant articular component, an olecranon osteotomy will provide excellent visualization.
  - The osteotomy should be performed through the bare spot in the ulnohumeral articulation.
  - A chevron-type osteotomy with the apex distal is the preferred technique, and predrilling for the osteotomy repair is helpful.
  - The osteotomy should be performed with a micro-oscillating saw and completed with an osteotome.
- Finally, there are several extensor mechanism-sparing exposures such as the Bryan–Morrey or TRAP.
  - These are useful when a total elbow arthroplasty (TEA) may be considered, as the olecranon must remain intact.

Surgical Technique

- ORIF allows for direct visualization of the fracture and radial nerve, as well as anatomic reduction and interfragmentary compression, when appropriate.
  - Immediate weight bearing and range of motion are possible with a well-fixed fracture.
    - The exposure should be dictated by the fracture location.
    - The patient is positioned supine with a hand table, or in the lateral decubitus position depending on the approach to be

used.

  - Typical fixation is with a 4.5-mm plate and 8 cortices of fixation proximal and distal to the fracture, although fewer may be possible with a good working-length to plate-length ratio.
  - At times, dual plating, or long periarticular implants may be required.
- Intramedullary nailing minimizes disruption of the fracture biology and has potential biomechanical advantages.
  - The technique is preferred for pathologic fractures.
  - The patient is positioned supine or with the head elevated 30–40 degrees and a bump is placed under the scapula.
  - The incision is similar to the anterolateral deltoid-splitting approach to the proximal humerus.
  - The entry point may be through the rotator interval or may require splitting the supraspinatus fibers depending on the implant.
  - A guidewire is inserted across the fracture site.
  - Open reduction may be considered to avoid radial nerve entrapment in the fracture.
  - Reaming is generally avoided, and if performed, hand reamers should be used and pushed across the fracture site.
  - The implant should be countersunk beneath the articular surface proximally to avoid impingement.
  - The distal interlocking screws are placed using perfect circle technique with an open exposure to avoid nerve damage.
  - The musculocutaneous nerve is at risk with anterior–posterior screws while the radial nerve is at risk with lateral–medial screws.
- Meta-analyses comparing ORIF to IM nailing have found similar rates of union, nerve injury, infection, and need for reoperation.
  - There is a higher overall rate of complications related to IM nailing.
- In distal humerus fractures, ORIF is performed with the patient in

lateral decubitus or prone position with the arm over a bolster.

    - After exposure, the articular block is reconstructed and then attached to the metadiaphysis.
    - Fixation may be placed in a parallel or orthogonal configuration, typically with a direct medial and posterolateral plate.
    - Parallel plating has some minor biomechanical advantages, but clinical studies have not demonstrated a difference in outcomes.
    - Locking technology is reserved for osteoporotic bone or very short segments.
    - Ulnar nerve transposition is controversial and not universally performed.
  - Total elbow arthroplasty is an option for C3 distal humerus fractures in elderly patients.

Postoperative Care

- Humerus fractures are dressed with a soft dressing and permitted range of motion and weight bearing as tolerated if adequate fixation achieved.
- Distal humerus fractures are immobilized in a posterior mold splint for 7–10 d until the incision is healed, at which point active and active-assist range of motion is initiated.
- Weight bearing is delayed until bony consolidation.
- After TEA, a lifetime lifting restriction of 5–10 lb is present.
- Early rehab is focused on protecting the integrity of the extensor mechanism repair—no active extension or forced passive flexion for 6 wks.

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ELBOW FRACTURES AND DISLOCATIONS

LAUREN CROCCO

Elbow Anatomy and Pathoanatomy

The anatomy of the elbow joint comprises 3 articulations including the ulnohumeral joint, the radiohumeral joint, and the proximal radioulnar joint. The trochlea articulating with the highly conformed proximal ulna provides the primary bony stability of the elbow joint. The radial head is a secondary bony stabilizer of the elbow joint against applied valgus forces. The coronoid process is a restraint against anterior and varus displacement.

The surrounding ligamentous structures are vital to maintain the stability of the elbow joint. Specifically the ulnar lateral collateral ligament (LCL), which attaches to the supinator crest is an important restraint to varus and posterolateral instability. The medial collateral ligament (MCL), namely the anterior bundle which attaches at the sublime tubercle of the ulna, is the primary restraint against valgus and posteromedial rotary instability.

Clinical History

- Ninety percent of dislocations occur with posterior or posterolateral displacement of the forearm relative to the distal humerus after a fall on an outstretched hand.
- Rarer injuries include lateral and anterior displacements of the forearm.
- When the dislocation is associated with a fracture, it is deemed a complex dislocation, which carries a higher risk of redislocation,

recurrent instability, and loss of motion.

Physical Exam

- A patient with an elbow dislocation will present with a swollen and grossly deformed elbow held in a protected position.
- Prior to attempted reduction it is imperative to obtain multiple x-ray views of the elbow and perform a detailed motor and sensory exam.
- The wrist, DRUJ, and shoulder must be examined as well because the patient will have an ipsilateral injury 10–15% of the time.
- A neurovascular exam should be repeated after the closed reduction.

Imaging

- X-ray:
  - AP, lateral, and oblique plain films will demonstrate the direction of dislocation as well as associated fractures.
  - Postreduction AP and lateral films are required to ensure concentric reduction.
- CT: After reduction a CT scan may be obtained to better identify associated fracture fragments.

Reduction

- In order to safely reduce a dislocated elbow, adequate analgesia and relaxation is required.
  - The first maneuver is to apply inline traction to correct medial and lateral displacement of the elbow.
  - Next, supinate the forearm to clear the coronoid under the trochlea while flexing the elbow joint and applying firm pressure on the tip of the olecranon.

Nonoperative Management

- If there are no associated fractures, after the closed reduction the elbow is taken through a range of motion to determine stable arc of the elbow joint.
  - The elbow should be placed at 90 degrees of flexion and full pronation in a posterior splint for a brief period of immobilization.
  - Many recommend splinting for ~7 d while there is literature to support immediate range-of-motion protocols.
  - A prolonged period of immobilization is correlated with residual pain and loss of motion.
- Repeat x-rays are required at the first follow-up clinic visit to ensure the elbow remains concentrically reduced.
  - Begin ROM within the predefined stable arc and gradually increase with interval splinting or sling for comfort only.
- If the elbow remains unstable in full extension initially, extension increases can be made over longer time period; 3–6 wks. Passive ROM should be avoided.
- If there is >40 degrees of flexion contracture at 6 wks, night extension bracing can be started.

Terrible Triad

- The terrible triad is defined as a complex elbow dislocation with associated radial head and coronoid fractures.
- Patients with this injury are routinely treated with surgery because of the inherent instability from this injury pattern.
- Operative treatment includes ORIF of the coronoid, ORIF or replacement of the radial head, and repair of the LCL with possible repair of the MCL.

Posteromedial Fracture Dislocation

- This injury can be subtle and easily missed.
- It consists of an anteromedial fracture of the coronoid and a rupture of the LCL.
- Poor outcomes are associated with missed/conservative management of this injury.
- CT scans will help identify the medial coronoid fracture and assist with surgical planning.
- The coronoid fracture is fixed through a medial approach via small plates and screws, and the LCL injury is repaired back to the humerus with anchors or drill holes.

Surgical Technique (Terrible Triad)

- The Kocher approach (anconeus and ECU) should be utilized for the terrible triad injury.
  - Often times the coronoid can be fixed from the lateral side, but if unable to be visualized, will need medial approach to have access and visualization.
- If the coronoid fragment is small and remains attached to the anterior capsule, it can be fixed to the ulna with grasping sutures and drill holes.
  - The use of an ACL drill guide can assist in the creation of these tunnels.
  - If the fragment is larger, it can be fixed by small cannulated retrograde screws.
- If the radial head is able to be fixed, it should be done with countersunk screws after anatomic reduction.
  - If the fracture is too comminuted to allow ORIF, the radial head should be replaced.
  - The radial head should not be excised in the setting of a terrible triad injury as the radial head is required for valgus stability.
  - During radial head replacement, the fractured radial head should be used as a template for head size selection to ensure the joint is not overstuffed.

- The LCL is usually avulsed from its proximal attachment and can be reattached to the lateral epicondyle with either suture anchors or transosseous sutures.
  - If the elbow is stable at this point in the operation from 30 degrees to full flexion repair of MCL is not necessary.
  - If it remains unstable the MCL must also be repaired with suture anchors or transosseous tunnels.
- Before leaving the operating room the elbow should be ranged under fluoroscopic imaging to ensure stability and concentric reduction of the joint.

Postoperative Rehabilitation

- Postoperatively the elbow should be splinted in 90 degrees of flexion and pronation if only the LCL was repaired.
  - If both the LCL and MCL have been repaired, the elbow can splint in neutral rotation.
- The period of immobilization lasts only 2–5 d and the patient can begin supervised ROM exercises including full rotation at 90 degrees of flexion and flexion/extension within a predetermined safe arc, avoiding terminal extension.
  - Gradual increase in extension is allowed as healing progresses.
  - Stiffness and heterotopic ossification are frequent postoperative complications.

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FOREARM TRAUMA

DAVID S. WELLMAN

Osseous Anatomy and Pathoanatomy

The forearm is composed of the radius and ulna and functions like a joint, with rotation between the bones forming the key motion for pronation and supination at the wrist. In the diaphyseal section of the bones, the interosseous membrane provides stability to the articulation and allows the radius to rotate around the ulna. The radial bow is essential to this relationship and can be estimated with the technique of Schemitsch and Richards for surgical planning. Multiple authors have documented the relationship between angular deformity and loss of rotation, stressing the need for anatomic reduction of alignment and rotation when addressing forearm fractures. The flexor/pronator mass takes origin from the medial condyle of the distal humerus; the extensors take origin laterally.

Clinical History

- Deformity and pain are usually readily apparent on physical exam, and patients report either direct trauma or a fall to an outstretched extremity.
- The direct blow is usually the mechanism of an isolated ulna fracture, commonly called a “nightstick” fracture.
- In the elderly, falls to outstretched arms are much more frequently associated with injuries to the distal radius.

Physical Exam

- Diaphyseal injuries are commonly associated with high-energy trauma.
- After ATLS protocols have been followed, the extremity should be evaluated for evidence of open injury.
- Neurovascular status must be confirmed, and an evaluation for compartment syndrome should follow.
- Diaphyseal injuries are commonly associated with injuries to the elbow and wrist, and a full exam of these joints is mandatory.
- Multiple reduction attempts in the acute setting should be avoided in adults, as most displaced diaphyseal fractures will be indicated for surgery.

Imaging

- Plain x-rays are typically all that is needed for a workup of diaphyseal injuries.
- AP and lateral views of the forearm, elbow, and wrist are mandatory secondary to the frequency of associated injuries at these joints.
- Care should be paid to angulation, shortening, and rotation of the fracture fragments.

Classification

- The AO/OTA classification is useful for research purposes, and most surgeons use standard description techniques to describe the injuries and communicate with colleagues.
- Open injuries are classified using the Gustilo Anderson system, and soft tissues can be classified using the Tscherne system.
- Isolated radius fractures should raise suspicion for a Galeazzi fracture, which is a radius diaphyseal fracture with associated distal radial ulnar joint (DRUJ) injury.
- Isolated ulna fractures should be scrutinized for Monteggia fracture dislocations, which comprise a proximal ulna fracture with radial head dislocation.

- Monteggia fractures are further classified using the Bado system as follows:
  - I—anterior dislocation of the radial head
  - II—posterior radial head dislocation
  - III—lateral radial head dislocation
  - IV—associated proximal radius fracture

Indications for Surgery

- Fracture of both diaphyseal radius and ulna
  - Conservative management of this injury in adults is poorly tolerated with high rates of reduction loss and malunion.
  - Surgery is nearly universally indicated in both-bone diaphyseal fractures; conservative treatment is reserved for the severe medically compromised patient.
- Fracture of the diaphyseal radius alone
  - ORIF is indicated for Galeazzi fractures in adults nearly universally.
  - This is known historically as the fracture of necessity secondary to poor outcomes from nonsurgical management.
- Fractures of the diaphyseal ulna alone
  - ORIF of the ulna with radial head reduction is indicated for Monteggia pattern injuries.
  - Typically, if the radial head is not reducible, the reduction of the ulna must be reevaluated prior to any open procedure to address the radius dislocation.
  - In the nightstick injury (ulna fracture alone without elbow or wrist involvement), conservative management can be undertaken if there is $>50\%$ overlap of the fracture edges and <10 degrees of angulation. Casting and functional bracing have had good outcomes in this setting.

Surgical Technique

- **Equipment**
  - Radiolucent arm board, tourniquet, 3.5- and 2.7-mm plate and screw sets, reduction clamps, fluoroscopy
- **Radius**
  - The classic approach for treating radius diaphyseal injuries is the Henry.
    - Dissection is taken through the skin, manipulating the neurovascular interval between the brachioradialis muscle (radial nerve) and the flexor carpi radialis distally (median nerve) or the pronator teres (median nerve) proximally.
    - Superficial radial nerve should be identified and protected under the brachioradialis muscle.
    - Branches of the radial artery will need to be ligated and the artery retracted ulnarly to expose the bone.
    - For proximal dissection using the Henry approach, the supinator will need to be released from its insertion on the radius with the arm in full supination to protect the posterior interosseous nerve (PIN).
    - In the middle third of the arm, the pronator teres will need to be released to expose the bone; this is typically done with the arm in pronation.
    - In the distal third, the pronator quadratus and flexor pollicis longus cover the radius and will need retraction.
  - For proximal fracture of the radius, the Thompson approach is often selected for control of the PIN and access to the proximal aspect of the radius.
    - The incision is in a line from the lateral epicondyle of the humerus to Lister tubercle.
    - The plane is between extensor carpi radialis brevis and the extensor digitorum communis.
    - The division between these muscles is often easier to find distally and trace proximally.
    - Deep dissection requires identification of the PIN.

        - This is easiest to find as it exists between the heads of the supinator; the nerve can then be traced proximally through the muscle to protect its branches.
    - The arm is then supinated and the supinator is detached from the radial insertion to expose the bone.
- **Ulna**
  - The plane between the extensor carpi ulnaris and flexor carpi ulnaris is utilized for this approach.
    - The bone is subcutaneous at this level.
- Fractures are reduced with clamps and provisional K-wires.
  - Once anatomic restoration has been achieved, absolute stability is maintained with lag screws and compression plating. The 3.5-mm plate and screw sets are usually sufficient; locking screws have very limited roles in diaphyseal fractures, as interfragmentary compression is typically gained with cortical screws and LCDC plates.
  - Care should be made to restore radial bow.
- In the Galeazzi fracture, evaluation of the DRUJ should be performed after fixation of the radius.
  - Pinning of the DRUJ for 4–6 wks in supination versus fixation of the triangular fibrocartilage complex (TFCC) has been advocated when incongruity remains after radial fixation.
- In the Monteggia injury, the ulna should be reduced anatomically in order to reduce the radial head.
  - Any difficulty in obtaining radial head reduction should result in a revisitation of the ulna reduction.

Postoperative Rehab and Expectations

- Early, gentle range of motion is typically prescribed after fixation of the above injuries, except when pinning of the DRUJ is necessary in the Galeazzi setting.
- Active/active-assist and light-passive modalities in flexion, extension, pronation, and supination are begun within 2 wks of

surgery and continued until signs of healing are evident on x-rays, at which time, activity and weight bearing can be further advanced.

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DISTAL RADIUS FRACTURES

KEVIN O'HALLORAN

Distal Radius Anatomy and Pathoanatomy

The metaphysis of the radius begins to flare out ~3 cm proximal to the radiocarpal joint. The distal radius consists of 3 independent articular surfaces: the scaphoid facet, lunate facet, and sigmoid notch. The scaphoid facet and lunate facet support their respective carpal bones forming the radiocarpal joint. The sigmoid notch couples with its counterpart on the distal ulna to form the distal radioulnar joint (DRUJ). The distal radius and ulna have been described as consisting of 3 columns: the lateral radial column (containing the scaphoid facet and the radial styloid), the medial radial column (containing the lunate facet and sigmoid notch), and the ulnar column consisting of the triangular fibrocartilage complex (TFCC), the ulnar styloid, and the distal ulna. Robust ligamentous structures connect the radius to the carpus volarly and dorsally, and the TFCC and associated structures connect the distal radius and ulna. Physiologic compression volarly accounts for the thickened anterior cortex of the distal radius and the physiologic tension dorsally explains the thinner dorsal cortex. The normal distal radial inclination is 23 degrees. The palmar tilt averages 10–12 degrees. The radial height (distance from tip of radial styloid to a horizontal line drawn from the distal articular surface of the ulna) averages 11–12 mm. The average ulna and radius end within 1 mm of each other. Fractures can be intra- or extra-articular and can involve any or all of the aforementioned columns.

Clinical History

- Distal radius fractures account for 15% of all extremity fractures.
- There is a bimodal age distribution with elderly patients and

children accounting for the majority of distal radius fractures.

- High-energy injuries such as sports injuries and motor vehicle accidents account for the majority of the distal radius fractures in younger patients.
- Older patients often suffer distal radius fractures from low-energy falls.
- Patients experience swelling, pain, and deformity depending on the fracture configuration and displacement.

Differential Diagnosis/Associated Injuries

- Of distal radius fractures, 68% are associated with soft tissue injuries such as TFCC tears and tears of the carpal ligaments.
  - Obvious disruptions of carpal interosseous ligaments such as the scapholunate ligament require either pinning or repair.
  - Certain types of radial styloid fractures and those fractures that split the scaphoid and lunate facets of the radius are associated with scapholunate ligament tears.
  - Fractures of the ulna including the ulnar styloid may occur. Base of the ulnar styloid fractures may increase the risk of DRUJ instability by affecting the foveal attachment of the TFCC.
  - Some surgeons advocate for open reduction and internal fixation (ORIF) of fractures of the base of the ulnar styloid if there is clinical instability of the DRUJ, although this is controversial.
- Carpal bone fractures can also occur.
  - Nondisplaced carpal bone fractures are typically adequately treated by immobilization, but scaphoid fractures are the exception and may require internal fixation to allow earlier wrist mobilization.
- Acute median nerve dysfunction can also occur requiring urgent surgical release of the transverse carpal ligament.
  - Compartment syndrome of the forearm or hand from high-energy mechanisms requires urgent decompression.

Physical Exam

- The presentation of distal radius fractures varies based on the type and displacement of the fracture.
- There is typically mild to moderate deformity with swelling, ecchymosis, tenderness to palpation, and painful range of motion.
- Careful observation for open injuries should be undertaken.
  - Ensure the ipsilateral shoulder, elbow, and hand are carefully examined.
  - The median nerve function and sensory distribution should be examined thoroughly.
  - The median nerve can be contused, suffer deformity by fracture fragments, or can experience elevated pressures in the carpal tunnel; decreased nerve function should prompt carpal tunnel release during surgery.

Imaging

- The standard PA, lateral, and oblique x-rays should be obtained.
  - The PA film should be evaluated for radial inclination, radial height, and ulnar variance.
  - Also, any depression of the articular surface or interruption of the carpal rows should be evaluated.
  - The lateral film should be evaluated for palmar tilt, scapholunate angle, comminution of the metaphysis, and displacement of the intra-articular fragments.
  - The oblique film can better demonstrate the radial styloid and the posteromedial aspect of the lunate facet.
  - The tilted lateral view, taken with a bump under the hand to orient the radius 23 degrees, can evaluate the joint surface of the distal radius without the overlying shadow of the radial styloid.
- Images of the uninjured distal radius may be helpful to determine the patient's normal anatomy.
- CT scans can be used to precisely define the intra-articular

displacement of a fracture and allow the surgeon to appreciate the comminution and fragmentation often found in distal radius fractures.

Classification

- Numerous classification systems have been devised for distal radius fractures.
- Detailing each classification system and eponym is beyond the scope of this book; none are used routinely in practice.

Nonoperative Management

- The goal of the treatment of distal radius fractures is to have a wrist that allows the patient adequate motion, limits pain, and facilitates the activities of daily living by each individual patient.
  - The decision to pursue nonoperative management of distal radius fracture can be a complex decision.
  - Multiple sources have weighed in on the treatment of distal radius fractures and there is not yet a consensus for the ideal treatment of these fractures.
  - Factors that affect the decision include age and functional status, the type of fracture, the initial displacement, the quality of the reduction, and associated injuries.
  - The AAOS Clinical Practice Guidelines (CPG) give a moderate recommendation for operative fixation of fractures with postreduction radial shortening >3 mm, dorsal tilt >10 degrees, or intra-articular displacement or step-off >2 mm.
    - This suggests that fractures with displacement less than these aforementioned parameters can be treated by cast immobilization.
    - However, the assessment of stability plays a role in choice of treatment.
    - Unstable fractures may displace during cast immobilization forcing the surgeon and patient to reassess the nonoperative

management.

- Four additional factors play a role in stability: the degree of metaphyseal comminution, the quality of the bone, the energy of the injury, and the degree of initial displacement.
  - If nonoperative treatment is pursued, the AAOS CPG give a moderate recommendation for using rigid immobilization rather than removable splints and weekly x-rays are recommended as a consensus recommendation for the first 3 wks after reduction to assess for maintenance of reduction.
- Regardless of operative versus nonoperative treatment, displaced distal radius fractures should be reduced initially, immobilized in either a splint or cast, elevated, and iced.
  - Adequate anesthesia should be administered for the reduction. In children this often involves conscious sedation coupled with a hematoma block.
  - In adults, a hematoma block and intravenous narcotics are typically employed.
- Reduction maneuvers vary depending on the displacement of the fracture.
  - The initial maneuver recreates the initial injury to disimpact the fracture fragments followed by a maneuver to correct the deformity.
  - Well-padded splints are then applied.

Operative Indications

- The AAOS CPG give a moderate recommendation in favor of operative fixation of fractures with postreduction radial shortening >3 mm, dorsal tilt >10 degrees, or intra-articular displacement or step-off >2 mm.
- However, the same AAOS CPG give an inconclusive recommendation regarding whether to recommend operative intervention for patients >55 yrs of age.
- The surgeon should take into account the patient's age and functional status and the patient's expectations of her wrist's

function upon completion of treatment.

- Additional factors to consider when deciding on operative management include the following:
  - Multiple trauma
  - Contralateral injury
  - Carpal bone injuries requiring ORIF
  - Displaced intra-articular fractures with joint step-off >2 mm after reduction
  - Acute carpal tunnel symptoms
  - Open injuries
  - Severe volar or dorsal comminution foreboding a poor outcome with cast immobilization
  - Progressive loss of reduction during cast immobilization follow-up

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Surgical Techniques

- Numerous surgical options exist for addressing distal radius fractures including closed reduction percutaneous pinning, open reduction and percutaneous pinning, external fixation, ORIF with dorsal plating, volar, and/or column-specific plating.
- Volar locking plates are now the most commonly utilized surgical method.
- The advantages of ORIF are accurate restoration of bony anatomy, stable internal fixation, a decreased period of immobilization, and early return of wrist function.
  - Radial column plating can be performed for isolated radial styloid fractures.
  - Conventional plating relies on screw purchase in the bone and apposition of the plate to the bone.
    - These types of plates can be used volarly or dorsally.
    - When there is comminution, locking screws support the subchondral bone without relying on bony purchase.

- The newest generation of these volar-locking plates typically has 2 rows for screws distally that provide support for the subchondral bone.
- The restoration of volar stability is important secondary to the stronger radiocarpal ligaments attached to the volar surface and the compressive forces that act on the volar cortex.
- Volar integrity facilitates the adequate reduction of metaphyseal fragments against a stable volar buttress and helps prevent volar radiocarpal instability.

Surgical Technique for Volar-Locked Plating

- **Preoperative**
  - Supine on regular table with a radiolucent hand table set up on the operative side.
  - Position the patient at the lateral side of the table with the shoulder, hand, and elbow centered on the hand table with the shoulder abducted to 90 degrees.
  - Place a tourniquet proximally.
  - Place a bump and prep and drape in standard sterile fashion. Exsanguinate with gravity or elastic bandage.
- **Incision**
  - The modified Henry's (FCR) approach will be described.
  - Mark out a longitudinal incision over the FCR with a 45-degree curve distally at the wrist crease should this exposure be necessary.
- **Exposure**
  - Incise the skin down to the FCR sheath.
  - Incise the FCR sheath longitudinally.
  - Sweep the FCR ulnarly and the radial artery laterally.
  - The palmar cutaneous branch of the median nerve runs on the ulnar side of the FCR.

- Avoid this nerve by staying on the radial side of the FCR.
- Incise the floor of the FCR sheath longitudinally.
- Retract the FPL muscle belly ulnarly, portions of this muscle's origin on the volar aspect of the radius, and the interosseous membrane may have to be taken down to allow sufficient exposure for plate placement.
- Often the pronator quadratus has been partially disrupted by the fracture.
- The remains of this muscle are removed sharply from the radial border of the radius taking care to leave a cuff of tissue for potential repair.
- Depending on the chronicity of the fracture and the difficulty in achieving a reduction, the insertion of the brachioradialis on the radial styloid can also be partially or completely released.

- **Reduction and plating**
  - Reduce the largest and least comminuted fragments first; use K-wires to hold reduction.
  - Obtain images to verify reduction.
  - One can use sterile traction setup should it be necessary.
  - Place the distal 2 rows of screws and obtain fluoroscopic images to ensure they do not penetrate the dorsal cortex.
  - Obtain a tilted lateral view to ensure the screws are not intra-articular. Complete the placement of the radial shaft screws.
  - Obtain final images.
- **Closure and splinting**
  - Close the pronator quadratus if tissue quality permits, then close the subcutaneous tissue and the skin.
  - Most surgeons will place a volar splint to support the repair.

Postoperative Rehabilitation

- Follow x-rays to ensure maintenance of reduction.

- Continue elevation and finger range of motion during the early rehabilitation period.
- Variability exists among surgeons as to how long immobilization is needed postoperatively.
- The wrist is transitioned during the first 6 wks into a removable wrist splint and begins active wrist ROM.

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PELVIC RING INJURIES

JEFFREY S. EARHART

Anatomy and Pathoanatomy

Bone/Ligament

The pubis, ilium, and ischium fuse to form the innominate bone. The 2 innominate bones join to each other anteriorly at the pubic symphysis and posteriorly at the bilateral sacroiliac (SI) joints. This forms a bony ring whose stability is incurred by several ligamentous structures. The symphysis is the anterior articulation of the pubic rami in the midline and is stabilized by a fibrocartilaginous disc, and superior and arcuate ligaments. The anterior and posterior SI ligaments stabilize the posterior ring. The anterior SI ligaments are less robust while the posterior SI ligament complex is one of the strongest in the body and is vital to the stability of the ring. The sacrospinous ligaments run from the anterior sacrum and coccyx to the ischial spine and provide rotational stability in the axial plane. The sacrotuberous ligaments run from the posterolateral sacrum to the ischial tuberosity and confer rotational stability in the sagittal plane. Finally the iliolumbar and lumbosacral ligaments run from the fifth transverse processes to the posterior crest and sacral ala, respectively, to help provide vertical stability.

Neuroanatomy

The neuroanatomy of the pelvis is complex and comprises the somatic and autonomic systems. The lumbar and sacral plexuses comprise the somatic system, containing the ventral rami of T12–L4, and L4–S4, respectively. The lumbar plexus is located behind and within the psoas muscle compartment, forming several important named nerve branches: the iliohypogastric, ilioinguinal, genitofemoral, lateral femoral cutaneous, obturator, and femoral nerve. The sacral plexus exits the anterior sacrum and travels on the anterior surface of the piriformis and sacrospinous ligament, forming important named branches that exit the greater sciatic notch. Superior to the piriformis muscle exits the superior gluteal nerve while inferior to it exits the pudendal, obturator internus, posterior femoral cutaneous, sciatic, inferior gluteal, and quadratus femoris nerves (POP'S IQ). The pudendal nerve and nerve to obturator internus exit the pelvis via the greater sciatic notch and reenter it via the lesser sciatic notch. The femoral nerve runs between the iliacus and psoas muscles, exiting under the inguinal ligament in the muscular compartment lateral to the iliopectineal fascia. The L5 nerve root runs over the sacral ala ~1.5 cm medial to the anterior SI joint and can be at risk during anterior SI joint reduction and fixation or during placement of percutaneous SI screws.

The autonomic system is made up of the sympathetic and parasympathetic nerves. The sympathetic ganglia are located along the spinal column just posterior to the aorta and vena cava, continuing into the pelvis distal to the sacral promontory medial to the sacral foramen and converging toward the midline. The pelvic parasympathetics consist of a presacral plexus formed by fibers from the anterior rami of S2–S4.

Vascular Anatomy

The vascular anatomy of the pelvis comprises branches of the iliac vasculature, starting at the aortic bifurcation around L4–L5. These common iliac arteries then bifurcate again to form the internal iliac (hypogastric) and external iliac arteries. The external iliac continues under the inguinal ligament, medial to the iliopectineal fascia, to become the femoral artery. The internal iliac artery has multiple important branches including the obturator, superior and inferior gluteal, and internal pudendal arteries. Fractures involving the superior greater sciatic notch may risk injury to the superior gluteal artery. The corona mortis is a vascular anastomosis between the obturator and external iliac systems and can be associated with significant bleeding if injured from trauma or during surgery.

Sacral Dysmorphism

Variations in upper sacral morphology exist in up to 30–40% of the population. This must be identified during radiologic workup of the injured pelvic ring to prevent aberrant SI screw placement and injury to the nearby neurovascular structures. Several morphologic features are identifiable on plain radiographs, in particular the pelvic outlet and lateral sacral views. The S1 segment is not recessed from the pelvis and is seen at the level of the superior iliac crest. Prominent mammillary processes are present, representing residual transverse processes that have fused to the obliquely oriented sacral ala, whose slope is steeper than normal in both the coronal and sagittal planes. The superior neural foramina are large and irregular in shape, and a residual disc may be seen between the upper 2 sacral segments. The inlet view will show anterior cortical indentations at the level of the neural foramina, with a visible cortical density even further anterior to it, which represents the second sacral segment. Axial CT imaging may show a tongue-in-groove appearance of the SI joint. Finally, the iliac cortical density (ICD), normally collinear with the anterior alar cortex on lateral imaging and used to guide percutaneous SI screw placement, will be located caudal and posterior to the actual anterior ala.

Physical Exam

- Disruption of the pelvic ring results from high-energy mechanisms and can be associated with other significant injuries and hemorrhage.
- Evaluation of the injured pelvic ring should follow ATLS protocols with appropriate resuscitation and monitoring.
- Physical exam of the pelvic ring during the primary survey should be performed once by an orthopedic surgeon with assessment of stability in both the axial (rotational) and sagittal planes.
- The literature shows that physical exam of the pelvis is most sensitive and specific for detection of unstable injuries in the awake and cooperative patient (GCS $>$ 12).

Imaging

- The AP pelvic radiograph is utilized in ATLS as a screening tool for pelvic injury.

- When injury is suspected, further evaluation is warranted with inlet (AP stability) and outlet (vertical stability and sacral fractures) views, as well as a fine-cut CT scan (subtle posterior ring injury).
- Classic description of 45-degree inlet and outlet views has been questioned, with 25-degree inlet and 60-degree outlet angles appearing more accurate.

Classification

- **Tile/OTA:** Based on pelvic stability.
  - Type A fractures are stable injuries, usually avulsion fractures or isolated ramus fractures.
  - Type B fractures are rotationally unstable but vertically stable.
  - Type C fractures are both rotationally and vertically unstable.
- **Young–Burgess:** Based on mechanism of injury.
  - Each mechanism class has a continuum of injury with increasing instability.
  - Lateral compression (LC, "implosion") fractures are the result of a medially directed internal rotation force.
    - LC-1 fractures are stable injuries consisting of transverse ramus fractures anteriorly and an ipsilateral sacral buckle fracture posteriorly.
    - LC-2 fractures are unstable with a crescent fracture of the iliac crest that may involve a portion of the SI joint.
    - LC-3 fractures are called "windswept" and consist of an LC-1 or 2 on one side with an open book injury on the contralateral side.
  - Anteroposterior compression (APC, "open book") fractures are the result of a posteriorly directed external rotation force and are subclassified by the extent of the posterior ring injury.
    - APC-1 injuries are stable symphyseal disruptions without disruption of the pelvic floor or SI ligaments.
    - APC-2 injuries include disruption of the pelvic floor and anterior SI ligaments, but the posterior SI ligament complex remains

intact.

  - APC-3 injuries further include disruption of this posterior SI ligament complex resulting in global instability.
- Vertical shear (VS) injuries involve anterior symphyseal disruption or vertical rami fractures and vertical displacement posteriorly through the SI joint, sacral fracture, or iliac wing fracture.
- Combined mechanical (CM) injury results from a combination of other injury patterns.
- *Denis (sacral fractures):* Based on anatomic location of the fracture. This classification is prognostic for neurologic injury.
  - Type 1: Fractures lateral to the neuroforamina (6% risk to sciatic, L5)
  - Type 2: Fractures through the neuroforamina but not the central canal (28% risk to L5, S1, or S2).
  - Type 3: Fractures involving the central canal (60% risk, particularly to bladder, bowel, sexual function)
- **Stability:** A stable pelvic ring is able to support normal physiologic forces without displacement and is the primary indication for nonoperative treatment.
  - This is possible with a single disruption of the ring, which is generally anterior.
  - These include injuries classified as type A by Tile and LC-1 or APC-1 by Young and Burgess.
  - The literature has shown that static radiographs can underestimate the amount of initial displacement, and thus the classification and stability of the injury.
  - Some advocate for fluoroscopic exam under anesthesia to assess for occult instability in patients with incomplete injury to the posterior ring (Tile B; APC-1, APC-2, LC-1, LC-2, some LC-3).

Surgical Techniques

- **External fixation**

- Can be a temporary modality for the purposes of resuscitation, stabilization allowing other procedures, or pain control.
- It can also be used for definitive treatment when internal fixation cannot be performed.
- There are multiple fixator configurations that can be utilized.
  - **Iliac crest frame**
    - This involves multiple pins placed between the inner and outer tables of the ilium at the level of the gluteal pillar.
    - These pins can be placed rapidly without fluoroscopy using a K-wire placed along the inner table as a trajectory guide.
    - The outer cortex only should be drilled and pins should be blunt-tipped, placed by hand and kept about 4 cm apart along the crest.
  - **Supra-acetabular frame**
    - Pins are placed under fluoroscopic control in the strong pillar of bone between the AIIS and posterior-superior iliac spine (PSIS).
    - These pins have improved pull-out strength and hold SI joint reduction better than crest pins.
    - They sit lower on the abdomen, which allows better access for the general surgeon and increased flexion at the waist by the patient postoperatively.
    - The disadvantages include the increased time and need for fluoroscopy during pin placement, which makes this construct less useful in the emergency setting.
    - These pins do not control coronal rotation of the pelvis as well.
  - **C-clamp**
    - This device provides stability to posterior ring disruptions.
    - The pins are inserted at the intersection of a line connecting the ASIS to the PSIS at the boundary of its middle and posterior third (approximately at the level of the posterior greater trochanter).
    - This device is contraindicated in ilium fractures anterior to the

SI joint and care must be taken in the presence of a comminuted sacral fracture to avoid overcompression.

Anterior Ring Injuries

- **Symphysis**
  - Plate fixation is the primary modality of internal fixation to stabilize the anterior pelvic ring or to augment fixation of the posterior ring.
    - It is generally performed through a midline or Pfannenstiel skin incision and development of the space of Retzius.
    - The rectus abdominis muscles are generally retracted rather than detached, and the symphysis is reduced with an appropriate clamp while concurrently monitoring the posterior ring for any signs of displacement.
    - Retrospective data show that malunion rates are much lower with the use of a multihole plate rather than 2-hole plate.
    - A cadaveric study shows no advantage to the use of locked plates in rotationally unstable partial disruptions.
    - A 90–90 dual-plating construct is mechanically stronger but the literature has not shown this to be necessary for acute injuries.
  - **Ramus fractures**
    - Although controversy exists, minimally displaced ramus fractures are generally treated nonoperatively.
    - Widely displaced ramus fractures likely have a disruption of the strong iliopectineal fascia, with some surgeons advocating for fixation.
    - In complete ring injuries they may be fixed to augment posterior ring fixation.
    - The decision to use a plate versus intramedullary screws (antegrade or retrograde) depends on the injury pattern, surgeon preference, and location of the fracture.
    - Anteriorly based external fixation is also used to support ramus fractures and augment posterior fixation.

Posterior Ring Injuries

- **SI joint dislocations**
  - These injuries can be treated via anterior, posterior, or percutaneous approaches depending on the degree of displacement and concomitant injuries.
  - Regardless of the approach chosen, the surgeon must ensure the ability to obtain high-quality intraoperative AP, inlet, outlet, and lateral sacral fluoroscopic images.
  - Anesthesiologists should be asked to avoid use of nitric oxide to limit the production of bowel gas and improve intraoperative image quality.
  - The SI joint must be reduced anatomically using direct or indirect techniques prior to fixation.
- **Closed reduction percutaneous fixation**
  - This technique requires closed anatomic reduction of the SI joint, making it a more viable option in the first few days after injury.
  - The primary reduction maneuver is longitudinal traction, which can be applied with the patient prone or supine.
  - Fixation consists of iliosacral lag screws in the S1 and/or S2 segments placed percutaneously under fluoroscopic control.
  - SI screws are generally oriented from posterior lateral to anterior medial to ensure they are perpendicular to the SI joint.
  - Anterior screw perforation risks the L5 nerve root as it drapes over the sacral ala or the iliac vessels on the bony surface.
  - Posterior perforation risks the cauda equina and inferior perforation risks the S1 nerve root in its osseous tunnel.
  - In patients with sacral dysmorphism, the upper sacral segment safe zones are smaller and more oblique, requiring careful preoperative planning and possibly avoidance of fixation in this segment.
  - The S2 segment in dysmorphic sacra is often safe for screw placement but the surgeon should be prepared to utilize other methods of fixation.
- **Open reduction internal fixation**

- The indication for open reduction is the same as the contraindication to closed reductions: the inability to obtain high-quality fluoroscopic images for any reason, or the inability to obtain and maintain an anatomic reduction of the SI joint through closed means.
- Anterior approaches allow for supine positioning, excellent joint visualization, and avoidance of the posterior soft tissues; however, posterior pelvic translation can be difficult to control, and sacral fractures cannot be fixed through this approach.
- Fixation can consist of SI screws, anterior plates spanning the SI joint, or both; however, the L5 nerve root must be protected.
- A posterior approach is performed in the prone position through elevation of a full-thickness flap and elevation of the gluteus maximus off the posterior crest and thoracodorsal fascia without incision into the muscle itself.
  - This allows for placement of Weber reduction clamps posteriorly to control sagittal rotation and vertical displacement, and specialized pelvic clamps across the SI joint through the greater sciatic notch to provide compression.
  - Fixation of the reduced SI joint is usually with percutaneous iliosacral screws, though adequate fluoroscopic imaging is again a prerequisite.
  - In sacral fractures or osteoporotic patients, SI screws can be supplemented with a posterior tension band plate, which is usually a 14- or 16-hole reconstruction plate running across the posterior sacrum connecting the PSISs.

- **Crescent fractures**
  - Approach and fixation of a crescent fracture is dictated by the location of the crescent relative to the SI joint and the amount of involvement of the sacrum.
  - Usually, the crescent segment remains articulated with the sacrum via the SI ligaments, allowing for restoration of stability following anatomic reduction and fixation of the ilium using lag screws and plates via an anterior or posterior approach.
  - If the crescent is posterior to SI joint or there is significant sacral

involvement, a posterior approach is indicated.

  - Closed reduction techniques with percutaneous fixation of crescent fractures have also been described.

- **Sacral fractures**
  - Surgical indications for sacral fractures include contribution to pelvic ring instability, spinopelvic dissociation, significant kyphotic deformity, cauda equina syndrome, radiculopathy, and prevention of impending neurologic injury.
  - The later refers to fracture fragments within the neuroforamen, which may require operative removal to prevent nerve root injury during reduction maneuvers.
  - For vertical sacral fractures, the primary tools for reduction are longitudinal traction and adjustments to patient positioning.
  - The sacrum is approached posteriorly with careful soft tissue handling, and vertical fractures are typically fixed with sacral screws, which differ from SI screws in several ways.
    - The starting point is more anterior, allowing for passage perpendicular to the fracture rather than the SI joint.
    - Sacral screws are fully threaded position screws to avoid overcompression across fracture comminution or affected neuroforamina.
    - They can sometimes be placed as transiliac–transsacral screws, though the utility of this technique remains unknown.
    - These screws may be augmented with a posterior tension band plate or spinal–pelvic fixation (triangular osteosynthesis) in the setting of severe comminution or osteopenia, particularly if the L5–S1 facet is involved, to prevent late displacement.

OUTCOMES

- The Young–Burgess classification system has been shown to correlate with organ injury, transfusion requirements, and mortality, with APC-3 injuries having the greatest resuscitation requirements of these injury patterns.

- Historical studies have found death in patients with LC injuries to be more likely caused by closed head injury than hemorrhage or visceral injury, as noted in APC injuries. Such data help providers anticipate associated injuries and resuscitation needs in blunt trauma patients with pelvic fracture.
- Retrospective data have shown that the presence of any pelvic ring disruption following blunt trauma is an independent risk factor for mortality while others have shown that when these patients are hemodynamically unstable at presentation, independent predictors of mortality include age >60, ISS score, Revised Trauma Score (RTS), and need for blood transfusions.
- Several studies report functional outcomes of patients undergoing surgical fixation of pelvic fractures with reports of sexual and excretory dysfunction; however, a recent systematic review of this topic revealed inadequate literature to draw meaningful conclusions.

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ACETABULAR FRACTURES AND HIP DISLOCATIONS

LAUREN LAMONT

Acetabular Fracture

Acetabular Anatomy

The acetabulum, located between the pubis, ilium, and ischium, is composed of 2 columns. Letournel described the 2-column theory, with the columns as an inverted Y overlying the acetabulum. The anterior column includes the following: pubic symphysis, ramus, anterior wall, anterior half of the articular structure (dome, fossa, quadrilateral plate) to the anterior ilium. The posterior column includes the following: ischial tuberosity, greater and lesser notches, and the posterior half of the articular segment (dome, wall, fossa, quadrilateral plate). The dome of the acetabulum at the junction of the 2 columns is the weight-bearing region of the acetabulum. Important vascular anatomy when fixing acetabular fractures is the corona mortis should be identified when fixing acetabular fractures; it is the retropubic anastomosis between the external iliac (epigastric) and internal iliac (obturator) vessels. The superior gluteal neurovascular bundle exiting the sciatic notch can also be at risk.

Mechanism of Injury

Generally these fractures occur due to high-energy trauma, falls from height, motor vehicle or motorcycle accidents. In the elderly population they can be a result of a low-energy fall, but hip fracture is more common.

Clinical Evaluation

- These are high-energy injuries that often present as a trauma activation in the ER, so a full trauma workup indicated.

- Assessment of airway, breathing, and circulation according to ATLS protocol comes first, then orthopedic evaluation.
- Concomitant head, genitourinary, thoracoabdominal, spine, and hip injuries must be assessed, as over half of patients will have injury to another organ system.
- It is important to inspect soft tissues for Morel-Lavallée lesions, a degloving injury over the greater trochanter that can be associated with an acetabular fracture.
- The sciatic nerve runs posterior to the acetabulum and motor and sensory function must be fully evaluated.

Imaging

- **X-ray**
  - Five standard pelvic views should be obtained: AP, inlet, outlet, obturator oblique and iliac oblique. Iliac and obturator oblique (or Judet) views are specific to acetabular fractures.
  - Judet views are taken at an oblique 45-degree angle to the acetabulum in either direction.
  - Roof arc measurements are made on x-ray to determine the stability of the acetabular dome, as they are measured on the AP and Judet views. A vertical line from the center of the acetabulum and another line from the center to where the fracture intersects the acetabulum is drawn and the resultant angle measured.
  - Dynamic fluoroscopic exam in the operation room is used to assess hip stability.
- **CT**
  - Used to delineate involvement of the columns and walls. CT is critical to evaluate for marginal impaction of the articular surface.

Classification

- The Letournel classification is most commonly used.
- The classification is divided into simple (elementary) and combined (associated) fracture types.

- The elementary fracture types are posterior wall, posterior column, anterior wall, anterior column, and transverse patterns.
- Associated patterns include both column, posterior wall with column, T-type, anterior column with posterior hemitransverse, and transverse with posterior wall.

Nonoperative Management

- Indications for nonoperative management include stable fractures with a congruent hip joint, <2 mm of displacement, an intact superior dome with roof arc measurements >45 degrees (does not apply to posterior wall fractures) or medically unstable patients unable to tolerate the procedure.
- Acetabular fractures are managed nonoperatively with protected weight bearing for 6–8 wks and serial radiographs to assess displacement and fracture union.

Operative Indications

- Indications for operative fixation of acetabular fractures include >2-mm articular displacement, nonconcentric hip reduction, intra-articular fragments, marginal impaction, and unstable fracture such as a large posterior wall fracture.

Surgical Technique

- **Pre-op considerations**
  - Concomitant injuries that may affect positioning and patients' overall stability and ability to undergo a lengthy procedure must be considered.
  - Patient age and presence of hip osteoarthritis also play a role in determining the ideal procedure.
  - Generally fixation should be performed within the first 14 d so that fracture fragments are mobile.
  - Patients must be taken to the OR emergently if they develop a sciatic nerve palsy after reduction, have an open fracture, or an irreducible hip dislocation. Large intra-articular fracture fragments may also warrant an urgent trip to the OR for removal.
- **Surgical approaches**

- Surgical approach is based on the fracture pattern and ability to obtain a reduction through the given exposure.
- These include the Ilioinguinal, Kocher–Langenbeck, extended iliofemoral, and modified Stoppa approach.
  - The ilioinguinal gains expose through 3 windows (lateral, middle, and medial).
    - This approach is indicated in fractures of the anterior column or wall, anterior fracture with associated posterior hemitransverse, and some T-type, transverse and both column fractures.
- The Kocher–Langenbeck is a posterior exposure, which accesses the posterior wall and column, transverse, transverse-posterior wall, and some T-type fractures.
  - The most extensile approach is the extended iliofemoral, which carries a risk of heterotopic ossification.
    - This approach provides exposure of both columns and is indicated in associated fracture patterns in which both columns must be accessed for reduction.
- The modified Stoppa approach provides exposure of the quadrilateral plate.

Complications

- Complications of acetabular fracture with either operative or nonoperative management include posttraumatic degenerative joint disease, neurovascular injury, as well as blood clots.
- Post-op patients can also develop infection, bleeding, and heterotopic ossification.

Postoperative Rehab and Expectations

- Postoperatively, rehabilitation is based on the patient's injury, medical condition, and method of fixation. Toe-touch weight bearing is maintained for the first 10–12 wks while working on passive range of motion and isometric strengthening activities. After this, progressive weight bearing is initiated to advance to independent ambulation and strengthening by 3 mos.

Hip Dislocations

Hip Anatomy

The hip joint is composed of a ball and socket articulation between the femoral head and the acetabulum. Compromise of vascularity is important when thinking about a hip dislocation. The vascularity to the femoral head is supplied primarily by the medial femoral circumflex artery; both the lateral femoral circumflex and the obturator artery also have contributions. The major supply from the medial femoral circumflex artery enters the capsule through the retinacular arteries originating from extracapsular ring at base of femoral neck. The sciatic nerve also courses in close proximity to the hip joint.

Mechanism of Injury

The hip joint has both intrinsic bony and ligamentous stability. Due to this stability, high-energy trauma is needed to dislocate the femoral head from the acetabulum. The most common mechanism of injury is motor vehicle accident in which the knee impacts the dashboard with the hip flexed and adducted, resulting in a posterior dislocation. Hip dislocations can also result from a significant fall or work accident. Anterior dislocations occur secondary to trauma on an abducted and externally rotated hip, but they are far less common than posterior dislocations.

Evaluation

- A full trauma workup is the first priority when the patient presents to the emergency room.
- The patient with a hip dislocation must be examined for concomitant injuries, especially to the knee in a dashboard injury.
- An alert patient will be in significant discomfort with a hip dislocation; this can distract from other injuries, so a full survey should be performed after the reduction.
- Patients with a posterior dislocation will present with the leg in flexion, adduction, and internal rotation.
- In anterior hip dislocations, the leg will be in external rotation and some degree of flexion and abduction.

- These must be emergently reduced because a dislocated hip results in damaged articular cartilage and potential vascular compromise.
- Function of the sciatic nerve, especially the peroneal branches, should be evaluated, as well as the vascular status of the limb.

Imaging

- **X-ray**
  - An AP pelvis should be obtained immediately in a suspected hip dislocation looking for an incongruent hip joint.
  - The femoral head will appear larger than the contralateral hip in an anterior hip dislocation while in a posterior dislocation it will appear smaller.
  - The femoral neck should be well visualized in order to assess for fracture before performing a reduction maneuver.
  - A cross-table lateral view will also distinguish an anterior or posterior dislocation.
- **CT**
  - CT is useful in evaluating any concomitant fractures or intra-articular fragments, but due to urgency, it is generally done after reduction is performed.
  - CT after reduction is very helpful in ensuring no intra-articular fragments are present.

Nonoperative Management

- A native hip dislocation must be emergently reduced in order to preserve vascularity to the femoral head.
- Closed reduction may be performed under general anesthesia in an operating room to optimize relaxation.
  - If this cannot be done in a timely manner, a reduction under sedation in the emergency department should be performed; however, the goal is as complete relaxation as possible for a smooth reduction in order to minimize articular cartilage damage.
- An advantage of ER reductions is that further imaging such as CT

can be obtained to evaluate for an incarcerated fragment if the hip is irreducible before going to the operating room.

- Posterior reductions can be performed through the Allis maneuver.
- While stabilizing the pelvis, anterior traction is applied while an assistant applies countertraction in abduction and gentle internal and external rotation until finally the limb is adducted while maintaining traction.
- Most of the time a clunk is associated with the reduction that can be both felt and heard.
- Other techniques such as the Stimson and Bigelow have also been described.
- Once reduction is achieved the patient should be placed in a knee immobilizer to prevent hip flexion and potential redislocation.
- CT will aid in assessment of an associated posterior wall fracture.
- If the fracture is $< 20\%$ of the wall, the patient can typically be managed nonoperatively; however, dynamic fluoroscopy should be used to assess and confirm stability.

Operative Indications

- If closed reduction is unsuccessful, unstable, or associated with an incarcerated fragment, open reduction is emergently indicated.
- Longitudinal traction should be applied to the femur in the setting of incarcerated fragments if any delay to the operating room is expected.

Operative technique

- Approach has classically been performed in the direction of the dislocation; however, this is controversial.
- Concomitant femoral head and neck fracture may favor an anterior approach in a posterior dislocation.
- For posterior approach a Kocher–Langenbeck approach is used.
- Anteriorly, a Smith-Petersen can be utilized; however, concomitant fracture must be considered.
- Goals of surgery include evaluation of the articular cartilage of the

hip and acetabulum, removal of loose bodies, achieve a concentric reduction, and reduction and plating of any fractures.

Complications

- After hip dislocation the rate of osteonecrosis of the femoral head in the literature ranges from 5–40%; this number increases the longer the hip is dislocated.
- If there is significant damage to the articular cartilage, posttraumatic arthritis can develop.
- Traction to the sciatic nerve can result in injury, and about half of these resolve.
- Recurrent instability is rare but has been reported.

Postoperative Rehab and Expectations

- Both weight bearing and range of motion after hip dislocation are controversial.
- Initially, if stable reduction is achieved, the patient gradually progresses with weight bearing.
- In an unstable reduction, if the joint is concentric in traction, this can be maintained for 4–6 wks.

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PROXIMAL FEMORAL FRACTURES

J. STUART MELVIN

Epidemiology

Fractures of the proximal femur occur infrequently in young patients but are quite common in the elderly with $>$300,000 occurring in the United States each year. Typically, these are low-energy fractures through osteoporotic bone, often occurring from a ground level fall.

Anatomy and Pathoanatomy

It is important to distinguish between the regions of the proximal femur in which these fractures occur since this predicts healing capacity and the recommended treatment.

Femoral Neck fractures

These fractures are intracapsular and healing is slowed by synovial fluid. Additionally, fracture displacement often disrupts the ascending cervical branches of the medical femoral circumflex artery, compromising the blood supply to the proximal fragment. These factors combine to negatively impact the healing capacity of femoral neck fractures.

Intertrochanteric fractures

These fractures are extracapsular and occur through well-vascularized metaphyseal bone and have robust healing potential.

Subtrochanteric fractures

These fractures occur in the highest stress region of the body. They also occur in a metaphyseal–diaphyseal transition zone with less robust vascularity compared to the intertrochanteric region. Additionally, muscular forces on the proximal fragment lead to the fracture's flexed, abducted, and externally rotated posture. These factors combine to place tremendous load on internal fixation devices, compromise healing capacity, and hinder fracture reduction.

Classification

- Femoral neck fractures
  - The Garden Classification is most commonly utilized.
    - Type I—valgus impacted
    - Type II—complete, nondisplaced
    - Type III—partially displaced
    - Type IV—completely displaced
- Intertrochanteric fractures
  - Evans Classification divides IT fractures into Stable and Unstable based on whether the posteromedial cortex is intact.
- Subtrochanteric fractures
  - These fractures are rarely classified for informal communication.
  - The AO/OTA classification is most often utilized in research.

Clinical History

- These fractures are often the result of a low-energy fall in the elderly or high-energy trauma in the young adult.
- Assessment for syncope is important in the elderly while assessment for associated injuries is valuable in all patients.

Physical Exam

- Patients are unable to bear weight and typically present with a shortened and externally rotated extremity.

Imaging

- AP pelvis and hip or femur AP and lateral plain films are typically adequate.
- Traction and internal rotation can assist in determining the level of the fracture.
- MRI or bone scan are helpful in cases of suspected occult fracture.

Nonoperative Management

- Nonoperative management is rarely indicated.

Operative Treatment

- **Femoral neck fractures**
  - In the elderly, treatment is dictated by the fracture displacement and the patient's activity level.
  - Valgus-impacted or minimally displaced fractures are typically treated with percutaneous screw fixation.
  - However, nonunion and avascular necrosis can complicate up to 30% of these fractures.
  - Displaced fractures in low-demand elderly patients are treated with hemiarthroplasty, while high-functioning patients or patients with pre-existing arthritis are best treated with total hip arthroplasty.
    - It is important to remember that the dislocation rate is higher for total hip arthroplasty performed for femoral neck fracture compared to arthritis.
    - Femoral neck fractures in young patients are an orthopedic emergency.

        - In young patients, early open anatomic reduction and internal fixation has been shown in some studies to decrease the rate of avascular necrosis; the necessary timing of intervention remains controversial.
- **Intertrochanteric fractures**
    - Both the sliding hip screw and sideplate as well as the cephalomedullary nail have been successful in treating standard intertrochanteric fractures.
    - However, when considering implant cost and possible future conversion to total hip arthroplasty, the sliding hip screw is less costly and has lower complication rates during total hip conversion.
    - The sliding hip screw and sideplate is contraindicated in reverse oblique fractures.
- **Subtrochanteric fractures**
    - Cephalomedullary nails, recon nails, dynamic condylar screws, and 95-degree blade plates are acceptable treatment options.
    - Anatomic reduction and alignment is important, and open reduction may be necessary when utilizing nail fixation of the fracture.

Surgical Technique for Cephalomedullary Nail

- **Pre-op area**
    - Discuss anesthesia options with the anesthesia team.
    - Mark the operative site and initiate antibiotics.
- **Equipment**
    - Fracture table, 12-in fluoroscopy machine, cephalomedullary nail set
- **Positioning**
    - Supine on fracture table
    - Well-padded perineal post

- Ipsilateral arm secured over the chest with a pillow and tape
- Tilt torso away from the operative hip to allow more direct access to the trochanter
- Scissor the nonoperative leg down and bring fluoro in from the opposite side of the table
- Avoid lithotomy position due to compartment syndrome risk and difficulty with imaging

- **Procedure**
  - Ensure adequate AP and lateral fluoroscopy views before prepping and draping.
    - Make longitudinal 3-cm incision a hand's breadth superior and just posterior to the greater trochanter.
    - Obtain the starting point under AP and lateral fluoroscopy according to the technique guide.
    - Tap or drill the guidewire to below the lesser trochanter.
    - Confirm with fluoro.
- Protect the abductor insertion and open the proximal femur with the opening reamer.
  - Pass the guidewire across the fracture.
  - Confirm with fluoro that the guidewire is in the canal and measure for nail length.
- A lateral view of the knee is helpful for judging the correct nail length.
  - Ream 1.5 mm over the desired nail diameter if necessary.
  - Impact the nail into position.
  - Use the curve of the nail to your benefit during insertion and take care to avoid anterior cortical perforation distally.
- Insert the lag screw or blade according to the technique guide.
  - The tip of the screw or blade should be within 1 cm of subchondral bone and in the center or just inferior of center in the femoral head on the AP view and in the center of the femoral head on the lateral view.

- Place a locking bolt distally if indicated.

Postoperative Rehab and Expectations

- Most elderly patients may be allowed to weight bear as tolerated.
- Depending on the cortical integrity of the fracture reduction, younger patients may have their weight bearing protected if necessary.
- Emphasize to the patient and family, that the recovery process is slow for elderly patients and does not end with fracture union.

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FEMORAL SHAFT AND DISTAL FEMUR

BRIAN M. WEATHERFORD

Femoral Shaft

Epidemiology

These injuries may occur in patients of all ages; however, they tend to show a bimodal distribution. Young patients will typically have femoral shaft fractures secondary to high-energy trauma while elderly patients may sustain these injuries due to low-energy mechanisms such as a fall from standing height.

Exam

- Initial evaluation of any patient with a high-energy femoral shaft fracture should follow Advanced Trauma Life Support (ATLS) guidelines.
- A thorough neurovascular exam should be performed and documented.
- Patients with diminished or absent pedal pulses should have any gross deformity of the limb realigned.
- If the ankle–brachial index for the affected limb is < 0.9 following reduction, further evaluation and vascular surgery consultation is warranted.
- A systematic secondary survey should be performed, as patients are likely to have associated musculoskeletal injuries.
- Careful attention should be paid to associated soft tissue injuries about the knee.

- Any open fractures should be treated with tetanus prophylaxis, appropriate antibiotics, removal of gross debris, sterile saline lavage, and a sterile dressing.

Imaging

- Orthogonal views of the femur should be obtained for all femoral shaft fractures.
  - In addition, oblique views may help to identify the plane of greatest deformity and assist with operative planning.
- Dedicated views of the hip and knee should also be mandatory for every femoral shaft fracture to rule out noncontiguous injury, pre-existing implants, or deformity.
- Special attention should be paid to the femoral neck, as ipsilateral femoral neck fractures are seen in up to 10% of femoral shaft fractures.
- In some centers, management of high-energy femoral shaft fractures includes a fine-cut (2 mm) CT scan of the femoral neck to rule out ipsilateral neck–shaft fractures.
  - Most patients sustaining blunt trauma with a femoral shaft fracture will have a CT of the chest, abdomen, and pelvis performed on presentation.
  - Asking the radiologist or radiology technician to ensure that the CT includes the femoral neck can help rule out femoral neck fracture.

Classification

- Most commonly, femoral shaft fractures are classified descriptively based on the location of the fracture in the proximal, middle, or distal third of the femoral shaft.
- Additionally, the fracture pattern, angulation, translation, displacement, and any associated bone loss are helpful when describing these injuries.
- Fractures may also be described using the Winquist or the AO-OTA classification.
  - The Winquist classification is graded from 0 to 4 based on the amount of cortical contact of the femoral diaphysis.

- The AO-OTA classification is based on the bone involved (femur = 3) and the location (diaphysis = 2) and further subclassified based on fracture morphology.
  - Type A fractures are considered simple and include spiral, oblique, and transverse patterns.
  - Type B fractures are wedge fractures and include spiral wedge, bending wedge, and segmental wedge patterns.
  - Type C fractures are considered complex patterns that have no predicted cortical contact between the major proximal and distal fractures.

Operative Management

- The gold standard for management of femoral shaft fractures is reamed antegrade intramedullary nailing.
  - In patients who may have a delay until surgery, consideration should be given to placement of a distal femur or proximal tibia traction pin for patient comfort and to maintain limb length.
  - Patients may be positioned supine or lateral decubitus based on the overall patient status and surgeon familiarity.
  - In addition, patients may be positioned either on a fracture table or with the leg draped free on a radiolucent table.
    - When using a fracture table, the well leg may be placed either in the hemilithotomy position, abducted or scissored with dual leg traction to allow for intraoperative fluoroscopy.
      - The hemilithotomy position has been associated with compartment syndrome.
    - For patients on a radiolucent table, intraoperative adjuncts such as a 2-mm wire and tension bow or a well-placed femoral distractor may aid with maintenance of length and reduction.
- The entry portal for antegrade intramedullary nails varies based on the manufacturer as well as patient proximal femoral anatomy.
  - In general, the starting point for trochanteric entry nails is just lateral to the anatomic axis of the femoral canal on the AP view, and in line with the canal on the lateral view.

  - Typically this lies at the medial aspect of the greater trochanter on the AP view; however, trochanteric morphology may be variable, and alignment of the guide wire relative to the femoral canal should still be assessed.
  - Piriformis entry nails start in the piriformis fossa, a reliable radiographic marker that lies in line with femoral canal on the AP projection.
- Attention should be paid to maintenance of reduction while reaming and placing the implant, especially in infraisthmal fractures in which the nail will not affect a reduction.
  - In comminuted or transverse fracture patterns, special attention should be given to assessment of rotation and length.
  - Numerous fluoroscopic techniques exist for evaluating rotation and are discussed in the article by Krettek et al.
  - The well leg may also be prepped in to the field for direct comparison if needed.
  - Following proximal and distal interlocking, a final assessment of the femoral neck, limb alignment, rotation, and the ligamentous status of the knee should be performed.
- Retrograde nailing may also be performed for diaphyseal femur fractures.
  - Relative indications for retrograde nailing include multiply injured patients, bilateral femoral shaft fractures, ipsilateral femoral and tibial shaft fractures, distal femoral shaft fractures, and an ipsilateral acetabular fracture, pelvic ring injury, or femoral neck fracture.
  - The starting point for retrograde nailing is at the apex of Blumensaat's line on a true lateral view of the knee, and in the midpoint of the intercondylar notch on the AP view.
  - Proximal interlocking is performed free hand using the perfect circle technique and, if possible, interlocking should be performed proximal to the lesser trochanter to minimize risk to branches of the femoral nerve and profunda femoris artery.
- Plating of the femoral shaft may be used in certain circumstances.
  - Relative indications include a narrow intramedullary canal,

ipsilateral femoral neck and shaft fractures, pre-existing deformity, or periprosthetic fracture.

- External fixation of the femoral shaft is most commonly employed in a damage control setting to temporize injuries in patients whose physiology will not tolerate immediate intramedullary nailing.
  - In addition, patients with neurologic or vascular injury requiring repair, massive wound contamination or evolving soft tissue injuries may benefit from external fixation and repeat debridement prior to conversion to intramedullary nailing.
  - In the absence of pin tract infection, external fixation may be converted to an intramedullary nail within 2 weeks.

Outcomes

- Intramedullary nailing of femoral shaft fractures is a reliable procedure with union rates in large series ranging from 97–100% and infection rates from 1–3%.
- Series comparing modern retrograde and antegrade femoral nails have noted similar union rates. Hip discomfort with antegrade nailing may be seen in up to 10% of patients, and knee pain with retrograde nailing is seen in up to 36% of patients.
- Malunion is more commonly seen in patients with proximal or distal fractures in which the interference fit of the nail will not lead to a reduction.
- Malrotation of femoral shaft fractures treated with intramedullary nailing has been reported in up to 27% of fractures, although the amount of clinically significant malrotation remains controversial.
- In addition, heterotopic ossification may be seen at the entry portal site for antegrade nailing. This is symptomatic in only 5–10% of patients.

Distal Femur

Epidemiology

- Distal femur fractures represent $<1\%$ of all fractures and 3–6% of fractures of the femur.

- These injuries occur in a bimodal distribution with young patients suffering distal femur fractures from high-energy mechanisms such as a motor vehicle collision.
- Elderly patients may incur a distal femur fracture from low-energy mechanisms such as a fall from standing height.

Exam

- Initial evaluation of any patient with a high-energy distal femur fracture should follow ATLS guidelines.
- A thorough neurovascular exam of the affected limb should be performed and documented.
- Alert patients with isolated distal femur fractures may present with obvious pain, swelling, deformity, and inability to bear weight on the affected side.
- The soft tissue envelope should be carefully evaluated, especially the anterior skin proximal to the patella.
- Open distal femur fractures account for 5–10% of all injuries.
- With shortening at the fracture site, a diaphyseal spike from the proximal fragment may pierce the extensor mechanism and exit the soft tissues anteriorly.

Imaging

- High-quality AP, lateral, and oblique plain radiographs centered on the distal femur, as well as full-length femur films are necessary to initially assess the injury. In comminuted or shortened fracture patterns traction films may assist with preoperative planning.
- Fractures with intra-articular extension are best evaluated with thin-cut (2 mm) CT scans with coronal and sagittal reconstructions.
- Distal femur fractures have an associated coronal plane (Hoffa) fracture 38% of the time, which may be difficult to recognize on plain films.

Classification

- Distal femur fractures may be classified descriptively based on their anatomic location, with emphasis on articular involvement, unicondylar or bicondylar fracture patterns, and whether the fracture extends proximally into the diaphysis.

- Additionally, the fracture pattern, angulation, translation, displacement, and any associated bone loss are helpful when describing these injuries.
- Most commonly, the AO-OTA classification is used when discussing distal femur fractures.
  - Extra-articular fractures are classified as type A, with further subclassification based on the comminution and inherent stability of the fracture.
  - Partial articular fractures are classified as type B. B1 injuries involve the lateral condyle, B2 fractures involve the medial condyle, and B3 fractures are coronal plane (Hoffa) fractures.
  - Intra-articular fractures with complete detachment of the articular block from the shaft are classified as type C.
  - Simple articular and metaphyseal fracture patterns are C1 injuries, simple articular patterns with complex metaphyseal fractures are classified as C2, and complex intra-articular and metaphyseal fractures are C3 injuries.

Operative Indications

- Operative intervention is indicated for distal femur fractures to restore limb alignment and joint congruity, as well as to facilitate early range of motion to prevent joint stiffness and contracture.

Nonoperative Management

- Nonoperative management with bracing, casting, or skeletal traction is typically reserved for nonambulatory patients or those unable to tolerate surgical intervention.
  - Stable, nondisplaced fracture patterns may be managed with immobilization and protected weight bearing with frequent follow-up until union.
- Initial management of a distal femur fracture consists of a well-padded knee immobilizer or long posterior splint in isolated, low-energy patterns.
  - For those patients with multiple injuries, severe soft tissue wounds,

or significant shortening, knee-spanning external fixation may be indicated.

Operative Management

- Definitive operative management commonly utilizes either a laterally based fixed angle plate or a retrograde intramedullary nail with multiple interlocking screws in the distal segment.
  - The surgical approach and implant are dictated by the fracture pattern, overall patient physiology, and surgeon experience.
- Plating of simple intra-articular or extra-articular fracture patterns may be accomplished through a lateral approach to the distal femur.
  - More complex intra-articular fracture patterns may necessitate a lateral or medial parapatellar arthrotomy to reduce and rigidly stabilize the articular block.
  - Areas of metaphyseal comminution should be spanned with plates of adequate length to allow for relative motion and indirect bone healing in these areas.
- Retrograde intramedullary nailing may be utilized for extra-articular patterns with adequate distal bone stock, fractures with simple articular involvement once the articular component has been rigidly stabilized, and for periprosthetic distal femur fractures in which the femoral component has an adequately sized box to allow passage of a nail.
  - The starting point is located at the apex of Blumensaat's line in the sagittal plane and in the intercondylar notch in the coronal plane.
  - Fractures should be well reduced before reaming and nail placement since the nail will not effect a reduction in the metaphyseal femur.

Outcomes

- Surgical management of distal femur fractures results in improved knee motion, limb alignment, bony union, and functional outcomes when compared with nonoperative management.
- Surgically treated distal femur fractures have a nonunion rate of 6%, fixation failure rate of 3.3%, and deep infection rate of 2.7%.

- Secondary surgical procedures are needed in up to 16.8% of distal femur fractures. Focus has been placed on the incidence of nonunion in distal femur fractures managed with locked plating.
- Current locked plate designs may be too stiff to allow adequate motion in the metadiaphyseal region in order for callus formation to occur, with one recent study noting nonunion rates as high as 20% in distal femur fractures managed with locked plating.

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TIBIAL PLATEAU

BRIAN M. WEATHERFORD

Epidemiology

These injuries may occur in patients of all ages; however, they tend to show a bimodal distribution. Young patients will typically have tibial plateau fractures secondary to high-energy trauma while elderly patients may sustain these injuries due to low-energy mechanisms such as a fall from standing height.

Exam

- Initial evaluation of any patient with a high-energy tibial plateau fracture should follow Advanced Trauma Life Support (ATLS) guidelines.
- A thorough neurovascular exam should be performed and documented.
- Patients with diminished or absent pedal pulses should have any gross deformity of the limb realigned.
- If the ankle–brachial index for the affected limb is <0.9 following reduction, further evaluation is warranted.
- Compartments should be carefully evaluated.
- A systematic secondary survey should be performed, as patients are likely to have associated musculoskeletal injuries.
- For patients with low-energy unicondylar injuries, the coronal plane stability of the knee should be assessed with the knee in full extension to evaluate for instability secondary to displacement of the plateau.

Imaging

- High-quality AP, lateral, and oblique plain radiographs centered on the tibial plateau, as well as full-length tibia films are necessary to initially assess the injury.
- Tilting the beam ~10 degrees cephalad to caudad in the AP view will obtain a "plateau" view to better evaluate any articular incongruity.
- In comminuted or shortened fracture patterns, traction films may assist with preoperative planning.
- Fractures with intra-articular extension are best evaluated with thin-cut (2 mm) CT scans with coronal and sagittal reconstructions.
- It is important to obtain these images after any planned external fixation, should it be necessary.
- Plain films and CT scans should be scrutinized for the presence of a posteromedial coronal plane fragment in bicondylar fracture patterns.
  - This fragment has been shown to be present in up to 74% of bicondylar tibial plateau fractures and will affect surgical planning.
- Tibial plateau fractures have high rates of associated soft tissue injuries including meniscal tears and cruciate ligament injuries.
- Whether or not to obtain an MRI at the time of presentation remains controversial but may assist with operative planning.

Classification

- Tibial plateau fractures may be classified descriptively based on their anatomic location, with emphasis on articular involvement, unicondylar or bicondylar fracture patterns, and whether the fracture extends distally into the diaphysis.
- Most commonly, the Schatzker classification is used for tibial plateau fractures.
  - This classification is divided up in to 5 different types.

    - Type I is a pure split of the lateral plateau.
    - Type II is a split depression of the lateral plateau.
    - Type III is a pure depression of the lateral plateau.
    - Type IV is a medial plateau fracture of any kind.
    - Type V is a bicondylar fracture in which the tibial eminence remains attached to the diaphysis.
    - Type VI is a bicondylar plateau fracture in which no portion of the articular surface remains attached to the diaphysis.
- The AO-OTA classification may also be used when discussing tibial plateau fractures.
    - Extra-articular fractures are classified as type A, with further subclassification based on the comminution and inherent stability of the fracture.
    - Partial articular fractures are classified as type B.
        - B1 injuries are pure split fractures
        - B2 injuries are pure depression fractures
        - B3 injuries are split depression fractures
    - Intra-articular fractures with complete detachment of the articular block from the shaft are classified as type C.
        - Simple articular and metaphyseal fracture patterns are C1 injuries
        - Simple articular patterns with complex metaphyseal fractures are classified as C2
        - Complex intra-articular and metaphyseal fractures are C3 injuries

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Management

- Low-energy fracture patterns may be managed initially with a knee immobilizer and nonweight bearing.
- Operative indications are constantly evolving but typically consist of coronal plane instability >10 degrees, condylar widening, and

malalignment of the mechanical axis of the limb.

- The amount of articular depression allowed for conservative management is controversial and ranges from 2 mm to 1 cm.
  - Articular depression of the medial plateau is less well tolerated.
- Ultimately, the fracture must be interpreted in light of the patient, the associated injuries, and the surgeon’s ability.
- High-energy fractures may benefit from temporary knee-spanning external fixation to restore limb alignment until the soft tissue envelope is suitable for open reduction.
- Schatzker type IV fractures merit special mention as these fractures are commonly associated with multiple ligament injuries and may have associated vascular injuries.
  - The presence of a medial plateau fracture should alert the evaluator to the high-energy nature of the fracture.

- Management of operative tibial plateau fractures typically consists of open reduction with plate fixation.
  - Plates are typically applied in buttress mode.
  - A lateral approach extending from the lateral epicondyle of the femur to Gerdy tubercle and then distally over the anterior compartment is employed for fixation of the lateral plateau.
  - The lateral compartment musculature is elevated off the plateau from anterior to posterior.
  - A submeniscal arthrotomy may be performed to evaluate articular reduction and assess for meniscal injury.
  - Articular depression may be addressed either by booking open the lateral plateau fracture or through percutaneous techniques.
    - Screws are placed underneath the articular surface in a raft pattern to maintain articular reduction.
    - Indications for the use of locking plate technology remain unclear; however, locked screws may be employed in fracture patterns with significant medial cortical comminution to resist varus collapse.
    - Bicondylar patterns, especially those with a coronal plane

fragment, benefit from a separate medial plate placed through a separate posteromedial incision, as the medial plateau may not be captured adequately with a lateral plate.

Outcomes

- Satisfactory knee function may be obtained even with severe injuries.
- The tibial plateau appears to be more resistant to articular step-off than most articular fractures.
- Failure to restore the mechanical axis of the limb may lead to worse outcome and early arthritis.
- Historically, infection rates for operative management of plateau fractures were as high as 80%. Infection and soft tissue complications have greatly diminished with the advent of staged management and increased awareness of the soft tissue envelope.

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TIBIAL SHAFT FRACTURES

J. STUART MELVIN

Epidemiology

Fractures of the tibial shaft are the most common long bone fracture with 24% being open fractures. Road traffic accident is the most common mechanism.

Anatomy and Pathoanatomy

- The anteromedial surface of the tibia is immediately subcutaneous predisposing this bone to open fracture, especially Gustilo Type 3 open fractures.
- Additionally, with a less robust blood supply and thick cortical bone, healing times are often slower compared to other bones.
- The recent SPRINT trial cautioned against procedures for delayed union prior to 6 mos from injury since many procedures can be avoided by observing these fractures up to 6 mos.

Classification

- The fracture pattern is typically classified descriptively (transverse, oblique, spiral, comminuted, etc.).
- The OTA classification is more often employed for research.
- Open fractures are classified according to Gustilo and Anderson.

Clinical History

- A detailed history of the injury should be sought with a focus on the mechanism, setting as well as tetanus status.
- Time to administration of antibiotics is important for open fractures as dosing antibiotics within 3 hrs of open injury has been shown to decrease infection rates.

Physical Exam

- The initial evaluation should follow the Advanced Trauma and Life Support System protocol.
- Other injuries should be sought as over half of patients with open tibial shaft fractures will have additional injuries.
- Always remember compartment syndrome, even for open fractures, and assess neurovascular status.

Imaging

- Standard AP and lateral radiographs are adequate in most cases.
- MRI or bone scan are useful for suspected stress fracture.

Nonoperative Management

- Nonoperative treatment has generally lead to inferior results compared to operative treatment.
- Consider a long leg cast or functional brace for low-energy fractures with minimal displacement.

Operative Treatment

- Operative treatment has been shown to lead to lower nonunion and malunion rates, faster healing, and fewer secondary procedures compared to nonoperative management.
- Intramedullary nailing is the preferred operative treatment method for tibial shaft fractures.

- Plating may be indicated for certain proximal or distal fractures or periprosthetic fractures while external fixation is typically reserved for damage control situations.
- The SPRINT trial demonstrated a possible benefit to reamed nailing for closed fractures.
- Beware of extra-articular proximal third shaft fractures. Apex anterior and valgus malalignment is a common complication and special techniques may be warranted to prevent this complication.

Surgical Technique for Intramedullary Nail

- **Pre-op area**
  - Skin should be carefully inspected for open wounds and the patient evaluated for compartment syndrome by physical exam or compartment pressures.
  - Avoid nerve blocks, so that compartments can be assessed and dose preoperative antibiotics.
- **Equipment**
  - Radiolucent table, fluoro, tibial nail set, reduction clamps
- **Positioning**
  - Supine on radiolucent table.
  - A bump under the ipsilateral hip can help with leg rotation.
- **Procedure**
  - Begin by obtaining the nail starting point (just medial to the lateral tibial spine or in-line with the canal on the AP and at the anterior edge of the plateau on the lateral view).
    - Split the patellar tendon longitudinally in-line with its fibers or approach with a medial or lateral parapatellar incision.
    - Preserve the paratenon and protect the patellar tendon during reaming.
    - After reaming for the starting point, reduce the fracture and pass a ball-tipped guidewire across the fracture site.

- Well-placed bumps or percutaneously placed clamps or ball-spike pushers can assist with reduction.
- Advance the guide wire until it is in the center of the tibial plafond on the AP and lateral views.
- Measure for the nail length.
- Confirm measurement with lateral view of the knee.
  - Ream 1.5–2 mm over the anticipated size of the nail.
  - Pass the nail.
  - Place interlocking bolts from the medial side of the leg.
  - Place in a well-padded short leg splint with the ankle in neutral dorsiflexion.

Postoperative Rehab and Expectations

- The patient will remain nonweight bearing until evidence of fracture healing (typically 6–12 wks).
- The postoperative splint should be removed by 2–4 wks and ankle range of motion begun at that time.

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ANKLE AND PILON FRACTURES

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Anatomy

The ankle is a saddle joint with articulations between the tibia, talus, and fibula. The talus is almost entirely covered in cartilage and articulates with the medial malleolus and posterior malleolus of the tibia along with the lateral malleolus of the fibula. The talus is trapezoidal, and it is wider anteriorly than posteriorly. To accommodate the talus when dorsiflexed, the fibula externally rotates and laterally translates.

The medial malleolus osteoligamentous complex (MMOLC) is the primary stabilizer of the ankle and is made up of the medial malleolus and the deltoid ligament. The anterior colliculus (AC) is the origin of the superficial deltoid, which is more anterior, narrow, and distal than the deep deltoid and resists anterolateral rotation of the talus in plantar flexion. The 3 heads of the superficial deltoid are the naviculotibial (AC to dorsomedial navicular), the calcaneotibial (AC to sustentaculum tali), and the talotibial (AC to medial talar tubercle). The deep deltoid is more posterior, proximal, and broader. It originates from the intercollicular groove (ICG) and the posterior colliculus (PC). The 2 bands of the deep deltoid, the anterior talotibial ligament (ICG to medial talus) and the posterior talotibial ligament (PC to medial talus) resist anterolateral rotation of the talus when dorsiflexed.

The distal tibia includes the tibial plafond, the incisura fibularis, and the posterior malleolus. To accommodate the talus, the tibial plafond is concave and wider anteriorly than posteriorly. The metaphyseal region within 3 cm of the tibial plafond possesses the greatest compressive strength of the distal tibia. The incisura fibularis, a concave groove with which the fibula articulates, is restricted anteriorly by Chaput tubercle and posteriorly by Volkmann tubercle. There is variation in both the depth and width of the incisura fibularis between individuals. The posterior malleolus represents the posterior portion of the distal tibia and resists posterior translation of the talus.

The fibula is the lateral column of the ankle joint and is the origin of the lateral ligamentous complex (LLC) and of the insertions for the syndesmotic ligaments. The LLC has 3 ligaments. The anterior talofibular ligament (ATFL) prevents anterior subluxation of the ankle. It is the weakest of the three. The calcaneofibular ligament (CFL) prevents ankle inversion in dorsiflexion and is of intermediate strength. The posterior talofibular ligament (PTFL) prevents posterior rotatory subluxation of talus and is the strongest of the 3 ligaments.

The syndesmosis is the articulation between the incisura fibularis and the distal fibula. It stabilizes the talus against external rotation, and against lateral and axial translation. The anterior-inferior tibiofibular ligament (AITFL) originates from the Chaput tubercle and inserts into Wagstaffe tubercle on the fibula. The posterior-inferior tibiofibular ligament (PITFL) originates from Volkmann tubercle and inserts onto the posterolateral distal fibula. It contributes ~40% of the syndesmosis stability. The inferior transverse tibiofibular ligament is a cartilaginous structure that acts as a posterior labrum for the ankle; and the tibiofibular interosseous ligament (IOL) is a distal thickening of the interosseous membrane.

Pathoanatomy

Ankle Fractures

- Ankle fractures are typically caused by low-energy rotational injuries to a planted, inverted, or everted foot.
  - They are classically described by Lauge-Hansen with 2 components:
    - (1) the position the foot is in at time of injury
    - (2) the force exerted on the foot relative to the ankle at time of injury
    - They are further broken down into 4 injury patterns: Supination External Rotation (SER), Supination Adduction (SA), Pronation External Rotation (PER), and Pronation Abduction (PA).

- SER (40–75%): Supinated foot is externally rotated and the ankle progresses through the following injuries:
    1. AITFL rupture
    2. Short, stable, oblique distal fibula fracture running anterior-inferior to posterior-superior at level of syndesmosis with an AITFL midsubstance rupture, an avulsion of Chaput tubercle or avulsion of Wagstaffe tubercle
    3. PITFL rupture or a posterior malleolus fracture
    4. Unstable distal fibula fracture and a medial malleolus and/or deltoid ligament rupture
- SA (20%): Supinated foot is forcibly adducted and progresses through the following injirues:
    1. Low transverse fracture of fibula below syndesmosis or a tear of ATFL
    2. Medial talar displacement → vertical medial malleolus fracture through medial axilla with impaction injury to medial tibial plafond
- PA (5–20%): Pronated foot is forcibly abducted, and the ankle progresses through the following injuries:
    1. Medial malleolus fracture and/or a deltoid ligament rupture
    2. Chaput avulsion fracture or an AITFL rupture
    3. Transverse or laterally comminuted/butterfly high fibula fracture (5–7 cm proximal to joint) + an anterolateral tibial impaction
- PER (20%): Pronated foot is forcibly externally rotated (most common syndesmosis injury mechanism), and the ankle progresses through the following injuries:
    1. Medial malleolus fracture and/or a deltoid ligament rupture
    2. AITFL rupture or a Chaput tubercle avulsion
    3. High spiral fibula fracture (5–7 cm) running anterior-superior to posterior-inferior or a Maisonneuve fracture
    4. Posterior malleolus fracture or a PITFL rupture

- There are 3 posterior malleolus fragment subtypes:

- Posterolateral oblique
    - Medial extension
    - Small shell
  - The Danis–Weber classification of fibula fractures unfortunately cannot predict syndesmosis stability.
    - Weber A: Fibula fracture below level of syndesmosis
    - Weber B: Fibula fracture at level of syndesmosis
    - Weber C: Fibula fracture above level of syndesmosis

Pilon Fractures

- Pilon fractures can result from low-energy rotational injuries with spiral fracture patterns, minimal comminution, and soft tissue injury.
  - They may also result from high-energy axial loading injuries with significant comminution that transmits the force of the fracture into the soft tissues.
    - This results in significant soft tissue injuries.
  - The fracture pattern is partly dependent on foot position during load application, with dorsiflexion, neutral or plantar flexion generating anterior comminution, central comminution, or posterior comminution, respectively.
- Fractures are classified using the Ruedi and Allgower and the AO/OTA classification systems.
  - Ruedi and Allgower:
    - Type I are nondisplaced and noncomminuted
    - Type II show articular displacement without fracture comminution
    - Type III have both articular displacement and fracture comminution
  - AO/OTA:
    - 43-A: Extra-articular
    - 43-B: Partial articular

    - 43-C: Total articular
- Fractures of the tibial plafond are typically variations on 3 primary fracture fragments:
  - Medial malleolar fragment
  - Posterolateral fragment (Volkmann fragment)
  - Anterolateral fragment (Chaput fragment)
- Further comminution is created by secondary fracture lines.
  - Ligaments usually do not rupture in these injuries; therefore, each of these fragments will retain connections to their respective ligaments.
  - With more high-energy fracture patterns there will also be an area of central impaction.
  - Ninety percent of tibial plafond fractures are associated with fibula fractures.

Clinical History

- Injuries associated with ankle fractures include Achilles tendon ruptures, metatarsal fractures, lateral process of talus fractures, and anterior process calcaneus fractures.
- Injuries associated with pilon fractures include open wounds (20–40%), compartment syndrome, vascular injury, and concurrent lower extremity fracture.
- Five percent to 10% of pilon fractures are bilateral, 30% have an ipsilateral lower extremity injury, and 15% have spine, pelvic, or upper extremity injuries.

Physical Exam

Ankle Fractures

- Inspection of the ankle should consist of evaluating the soft tissues for blistering. It should also evaluate for tenting of the skin or skin at risk, open wounds (openings over the medial malleolus are suggestive of lateral ankle fracture dislocations), swelling, ecchymosis, or tenderness to palpation over the medial malleolus.

- The last 3 findings are 57% sensitive and 59% specific for deltoid ligament ruptures.
- Palpation of the soft tissues should include pulses (dorsalis pedis and posterior tibial artery), evaluation of both sensation and motor function, palpation of the proximal tibia to evaluate for Maisonneuve fractures, and evaluation of the syndesmosis by performing the "Squeeze Test."

Pilon Fractures

- Physical exam for pilon fractures is similar to that of ankle fractures, but with greater attention being paid to the soft tissue envelope.
- Focus should be on swelling and blistering, as well as exam for vascular compromise and compartment syndrome.
- Displaced fracture fragments and exposed bone in open fractures should be manually reduced to take ischemic pressure off of skin.
- Pilon fractures have a higher incidence of open wounds with up to 6% occurring in low-energy injuries and up to 50% occurring in high-energy injuries.
- Open fractures are graded by the Gustilo and Anderson System while closed soft tissue injuries are classified by the Tscherne and Goetzen System.

Imaging

Ankle Fractures

- ***Plain films***
  - Ankle AP/Lat/Mortise.
  - Evaluate for fibular length on AP view, on mortise view with the talocrural angle (normal is 83 degrees + 4 degrees), or the Shenton line of the ankle.
  - Evaluate the integrity of syndesmosis on AP view with tibiofibular clear space (TFCS) widening of >5 mm or tibiofibular overlap

(TFO) of <10 mm, on mortise with TFO <1 mm (all measured at 1 cm above the joint line), or on lateral views with subluxation of the talus.

- Assess for possible deltoid ligament injury with medial clear space widening >4–5 mm or with >1–2 mm talar shift on an ER stress test or gravity stress test.
- Evaluate the posterior malleolus fracture with an externally rotated lateral to capture the fragment in line with its fracture plane.

- ***CT scans***
  - Characterized posterior malleolus fragments, tibial plafond involvement, and associated talus fractures.

Pilon Fractures

- ***Plain films***
  - Ankle AP/Lat/Mortise, with complete radiographic evaluation of the injured extremity.
  - Plain films of the hindfoot and tibial diaphysis are important for characterization of any concurrent calcaneus fractures and tibial diaphyseal extension of the fracture.
- ***CT scans***
  - Performed after initial external fixation with ligamentotaxis to better characterize the fracture pattern for surgical planning.

Nonoperative Management

Ankle Fractures

- Isolated, nondisplaced lateral malleolus fractures with an intact MMOLC may be treated nonoperatively.
- Treatment consists of 6 wks in CAM boot, WBAT, with concurrent physical therapy for ROM exercises.
- ***Initial closed reduction***
  - (1) Hematoma/intra-articular block
  - (2) Quigley maneuver

    - With patient supine, hang the foot from the great toe and tie off medially across the body.
    - Allow the lower extremity to fall into abduction, this forces the foot to fall into relative internal rotation, supination, and adduction reducing the talus into the mortise.
  - (3) Placement into a 3-point–molded posterior U splint.

Pilon Fractures

- Nonoperative management is indicated for displaced fractures in patients who are not surgical candidates or are nonambulators.
- Treatment of nondisplaced fractures consists of closed reduction and casting with progressive weight bearing >10–12 wks as determined by fracture healing.
- Treatment of displaced fractures consists of calcaneal pin traction followed by casting.

Confounding Factors of Operative Management

- **Soft tissue swelling**
  - Operating through swollen soft tissues and/or hemorrhagic fracture blisters dramatically increases wound complications.
  - Diabetes: Patients with diabetes have a higher rate of wound complication versus the general population.
    - They will require atraumatic soft tissue handling, more extensive internal fixation, and prolonged immobilization and nonweight bearing (twice as long as general population).
- **Osteoporotic bone**
  - Locking plates and intramedullary fibular fixation are advantageous in the treatment of osteoporotic bone.

Operative Management

Ankle Fractures

- **Indications**
  - Unstable ankle fracture, syndesmotic diastasis, failure of nonoperative treatment, articular surface incongruity, or plafond impaction.
    - Indications to fix posterior malleolus fractures are >25% involvement of the articular surface, >2-mm displacement, posterior subluxation of talus, or if the fracture prevents other reductions.
    - Fixation of medial and lateral malleolus fractures returns 73% stability to the ankle, with syndesmotic fixation returning 100%.
      - Small medial malleolus fractures (<1.7 cm in width) will have concurrent deep deltoid rupture and will require syndesmotic fixation or deltoid repair for improved stability.
      - Those with medial malleolus fragments >1.7 cm in width but <2.8 cm in width must be stressed after medial and lateral malleolus fixation to assess the deltoid ligament.
      - Those >2.8 cm in width still require stress exam after fixation but will likely have an intact deltoid ligament.
    - Malreduced and short fibulas can lead to persistent medial clear space widening.

Pilon Fractures

- ***Indications***
  - Any articular incongruity, talar subluxation, or angular deformation.
- ***External fixation***
  - As a temporizing measure, tibiotalar spanning external fixators grossly restore length, rotation, and alignment via ligamentotaxis, which relocates the talus, and allows soft tissue to rest until definitive ORIF.
  - Benefits of an Ex-Fix include avoiding the zone of injury, not complicating future incision sites with pre-existing pin sites, and ease of application.

- When staging a pilon fracture with an Ex-Fix—it has fallen out of favor to perform ORIF of the fibula at the time of Ex-Fix placement. This is because surgical planning is based on the CT scan taken after fixator placement, and poorly placed fibular incisions can interfere with later definitive surgeries.

- ***ORIF***
  - Ruedi and Allgöwer's principles are the following:
    - (1) A construct with absolute stability
    - (2) Achieving interfragmentary compression of articular fragments with <2 mm of step-off
    - (3) Restoration of alignment in all 3 planes
    - (4) Early joint motion
    - (5) Skin is ready for definitive surgery when decreases in swelling allow skin wrinkling and blisters have reepithelialized

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Surgical Technique

- **Pre-op holding**
  - Confirm history, allergies, and exam of soft tissues.
  - Be aware of anesthesia plan, antibiotics.
  - Obtain consent and mark operative site.
- **Positioning**
  - Supine with contralateral hip bump for medial malleolus exposure, bump can be removed to access lateral malleolus.
  - Posterior malleolus can be approached with patient in the supine or prone position.
  - For pilon fractures, positioning depends on the fracture pattern, soft tissue condition, and the choice of approach.
    - Typically the patient is placed supine and an ipsilateral hip bump is used to neutralize leg rotation.
  - Posteromedial approaches require external leg rotation achieved via a contralateral hip bump and posterolateral approaches may

require the prone position.

Surgical Approaches

- Placement of skin incisions for pilon fractures is determined by fracture pattern rather than the 7-cm rule.
  - Efforts should be made to go between the anterior, posterior, and peroneal angiosomes of the distal tibia, and to allow adequate soft tissue rest prior to surgical fixation.
  - The tibial plafond can be accessed from multiple approaches to take advantage of these divisions and all approaches should be well planned prior to surgery.

Distal Tibia

- **Anteromedial approach to the distal tibia**
  - Advantage
    - Extensile exposure for medial and central plafond fractures, distal tibial metaphysis, and the medial malleolus.
  - Disadvantage
    - Large skin flap for wound coverage.
    - No true internervous plane, structures at risk include the deep peroneal neurovascular bundle.
- **Anterolateral approach to the distal tibia**
  - Advantages
    - Well-vascularized soft tissue flap that allows access to the Chaput fragment, which can be externally rotated on the AITFL to expose the central and posterior plafond.
  - Disadvantage
    - Poor visualization of medial comminution.
    - Internervous plane is between the superficial peroneal nerve (SPN, peroneal muscles) and the deep peroneal nerve (DPN, extensor muscles).
    - Structures at risk include the SPN subcutaneously as well as the

DPN and anterior tibial artery at the anterior of the ankle joint.

- **Posteromedial approach to the distal tibia**
  - Advantage
    - Allows access to posterior comminution or posteromedial fragments.
    - No true internervous planes but has multiple windows.
      - One window is between the tibial neurovascular bundle and the flexor digitorum longus.
      - Another is between the FDL and the tibialis posterior.
      - The third is anterior to the tibialis posterior.
    - Structures at risk during retraction include the posterior tibial artery and tibial nerve.
- **Posterolateral approach to the distal tibia**
  - Advantage
    - Can be used to access posterior plafond and posterior fibula for fibular plating, allows access to Volkmann fragment, and can be used as a supplement to the anteromedial/anterolateral approach for exposure of the entire plafond.
  - Disadvantage
    - Limited by the lateral approach to the fibula and FHL stripping is necessary for exposure of the posterior malleolus.
    - The internervous plane is between the SPN (peroneal muscles) and the tibial nerve (FHL).
    - Structures at risk include the subcutaneous short saphenous vein and sural nerve anterior to the incision.
- **Lateral approach for lateral fibular plating**
  - Advantage
    - Subcutaneous distal ¼ of the fibula allows an incision directly over bone for ORIF.
    - The incision may be shifted posteriorly to allow posterior plating of the fibula and for use as a posterolateral approach for ORIF of the distal tibia.

- Disadvantage
  - Muscle stripping may be necessary.
  - No internervous plane.
  - The SPN is at risk and transfers from the lateral to the anterior compartment at 5–10 cm proximal to fibular tip.
- **Approaches to the medial malleolus**
  - Advantage
    - Exposure of the medial axilla, medial comminution, medial impaction, and OCDs of the talus.
  - Disadvantage
    - No internervous plane.
    - Structures at risk include the saphenous nerve and long saphenous vein anterior and subcutaneous to the medial malleolus and the tibial neurovascular bundle deep and posterior to medial malleolus.

Open Reduction and Internal Fixation

- **Lateral malleolus fractures**
  - Can be fixed with lateral or posterolateral plating or IM fixation.
    - Anatomic reduction is required at the level of the mortise/syndesmosis while nonanatomic reduction above the midshaft fibula can rely on distal syndesmotic fixation to stabilize the mortise.
    - After reduction, verify length and rotation fluoroscopically.
    - Fixation can be performed with an anterior to posterior lag screw and a lateral neutralization plate, a lag screw only technique if the length of the fracture obliquity is >3 times the width of the fibula, or with a posterior antiglide plate.
    - For comminuted fibula fractures, utilize bridge plating without periosteal stripping.
    - After screw fixation, assess for intra-articular penetration of screws on mortise view.
- **Medial malleolus fixation**

- Fixation determined by fracture pattern.
- Transverse fractures of the medial malleolus can be fixed by 2 screws, usually 3.5 or 4.0 mm in diameter.
- Vertical fractures seen in SA type injuries instead require an antiglide plate due to high shear load component.
- Small or comminuted fragments require buttress plates or tension band constructs.

- **Posterior malleolus fixation**
  - After fibular reduction and fixation, the posterior malleolus fragment can be reduced either directly or indirectly.
  - Direct reduction involves a posterolateral approach to the ankle and antiglide or posterior to anterior interfragmentary fixation.
  - Indirect reduction is performed with percutaneous placement of a reduction clamp and anterior to posterior interfragmentary fixation.
- **Syndesmosis fixation**
  - After medial and lateral malleolar reduction and fixation, an external rotation stress exam or Cotton test is performed.
  - If positive, syndesmotic fixation is performed.
  - The syndesmosis is reduced with the talus in dorsiflexion. Large reduction clamps should be used with caution as they can force a malreduction if not applied in the correct plane.
  - Fully threaded, unlagged screws are placed 1.5–2.0 cm proximal, and parallel to the joint in a 20–30 degrees trajectory anteromedially from fibula to tibia.
  - Internal fixation options include 3.5-mm versus 4.5-mm screws, tricortical versus quadcortical screw penetration, and single versus double screw fixation.
  - Bioabsorbable and tightrope fixation is controversial.
- **External fixator placement for pilon fractures**
  - Pin placement should be outside the surgical area of the second stage.
    - Two 5-mm Schanz pins are placed in the proximal tibia in an

anteromedial to posterolateral direction.

    - A calcaneal 5-mm Schanz pin is placed medial to lateral posterior to the calcaneal tuberosity.
    - Fluoroscopy is utilized to guide a 4-mm Schanz pin from medial to lateral across the medial, intermediate, and lateral cuneiforms if necessary.
  - Reduction maneuvers include traction, varus/valgus angulation, and anterior/posterior translation.
    - A proximal tibial to calcaneus bar is placed, then the fracture site is slightly overdistracted.
    - A proximal tibial to cuneiform bar is placed to prevent ankle dorsiflexion/plantar flexion and a calcaneal to midfoot bar is placed to control forefoot adduction.
- **Fibular ORIF**
  - For comminuted fractures, rely on stiffer bridging constructs such as 2.7-mm/3.5-mm DCP or precontoured periarticular distal fibula plates.
  - For spiral or oblique fractures, lag screws and neutralization constructs or antiglide constructs with tubular plates are sufficient.
- **Distal tibia ORIF**
  - Reduction can be assisted by replacing the cuneiform pin with a talar neck Schanz pin, overdistracting the joint, and allowing the talus to fall into plantar flexion.
    - The articular reduction sequence is initiated with fibular open reduction and internal fixation if anatomic length and rotation can be restored.
    - Then, reduction of the Volkmann fragment is performed to ensure accurately reduced syndesmosis, followed by reduction of the medial malleolar fragment to the Volkmann fragment, and central comminution/impaction reduction/grafting.
    - Finally, the Chaput fragment is reduced.
      - Provisional fixation with K-wires and clamps followed by interfragmentary screws and precontoured periarticular

distal tibial plates for metadiaphyseal fixation.
  - Drain placement to decrease pressure on incision and low-tension suturing technique (Allgöwer–Donati suture).

Postoperative Rehabilitation

Ankle Fractures

- Patients are kept nonweight bearing for 6–8 wks until fracture healing is appreciated on plain films.
- Patients requiring syndesmotic fixation for associated ligamentous injuries are immobilized longer.
- Patients should not operate an automobile for 9 wks after a right-sided ankle fracture.

Pilon Fractures

- Patients are kept nonweight bearing for 10–12 wks.
- After 10–14 d of immobilization, the patient is then transitioned into a fracture boot and both passive- and active-assisted range of motion is started.
- Progressive weight bearing is initiated at 10–12 wks.

Complications and Outcome

- **Wound complications**
  - Tibial pilon fractures, more so than ankle fractures, suffer superficial and deep wound complications due to the extent of the initial soft tissue injury.
- **Arthritis**
  - Posttraumatic arthritis is due to cartilage injury during acute rotational injury (microtrauma, chondral damage, osteochondral damage) or persistent joint incongruity after treatment.
  - Thirty percent of pilon fracture patients have progressive posttraumatic arthrosis, ankle stiffness, and chronic swelling.

- **Symptomatic hardware**
  - The subcutaneous nature of medial and lateral malleolus means that patients often complain of painful hardware.
  - Removal of syndesmotic screws is currently controversial.
- Nonunion or malunion
- Peroneal tendonitis
  - Posterior fibular antiglide plating increases risk.

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FAI, LABRAL TEARS, AND DIAGNOSTIC HIP ARTHROSCOPY

HASAN SYED • JAY BOUGHANEM

Introduction

Femoral acetabular impingement (FAI) and associated labral pathologies are sources of hip pain and a cause of progressive degenerative changes in the hip. Cam and pincer lesions found in FAI serve as bony substrates for the development of labral tears and can lead to early osteoarthritis. Cam lesions are bony prominences of the anterior-superior part of the femoral head. Labral damage from cam impingement occurs in the anterosuperior part of the acetabulum, causing separation at the cartilage–labrum junction (Type 1 labral tear). Pincer lesions represent overcoverage of the acetabular rim in which repetitive contact stresses against a normal femoral neck results in labral injury. In pincer impingement, the labral damage occurs peripherally as the labrum is crushed between the acetabular shelf and femoral neck (Type 2 labral tear).

Studies have shown that the labrum serves a key role in preserving normal joint function by sealing the hip joint to maintain lubrication and hydrostatic pressure. It also allows for the protective distribution of contact forces across articular cartilage. Removal or debridement of the labrum may, therefore, detrimentally alter its physiologic function and initiate pathologic changes within the hip. In patients with FAI who are surgically treated, those with labral refixation recover sooner and have better clinical and radiographic outcomes compared to labral debridement.

Clinical History and Presentation

- Patients typically present with groin pain, sometimes accompanied by clicking/popping/catching.
- Antecedent trauma to the hip is present only in a small subset of patients.
- Typically there is a gradual onset of symptoms, particularly in individuals who do deep hip flexion/squatting type activities repetitively.
- The "C" sign refers to when patients make a "c" with their hands and cup their groin and greater trochanteric region when pointing to the area where they are symptomatic.
  - Useful when identifying patients who have labral or FAI-related pathology.

Differential Diagnosis

Differential diagnosis includes hip arthritis, osteonecrosis, chondrolysis, stress fracture of the femoral neck, tight IT band and trochanteric bursitis, gluteus medius tear, iliopsoas and IT band tendinitis, adductor tendonitis, hernia, referred pain from lumbar spondylosis and radiculopathy, referred pain from urologic or gynecologic conditions including ovarian cysts, etc.

Physical Exam

Patient should be in comfortable, loose lower extremity clothing for exam. Exam of any weight-bearing joint should start with and is incomplete without gait assessment. Exam of any joint is incomplete without range-of-motion assessment. Passive range of motion is assessed if active range of motion is limited. Exam of any joint in Orthopedics should include an exam of the joint above and joint below, both clinically and radiographically. Hence, the following should be included as part of an overall hip assessment that comprises inspection, palpation, range of motion, and strength/stability.

Gait Exam

Inspect for antalgic gait, cadence, and abductor lurch

- Abductor deficient gait
  - Abductor strength is tested and both sides compared

Lumbar Spine Exam

- Range of motion: Pain with lumbar spine extension, lateral bend, combination of both (indicative of nerve root compression) versus pain with lumber spine flexion and straight leg raise (indicative of lumbar disc disease and herniation)
- Neurologic
  - Gross motor exam can include ankle dorsiflexion (L4), extensor hallucis longus test with great toe dorsiflexion (L5), and ankle plantarflexion (S1)
  - Sensory and motor nerves originating from L2–S1 levels
  - Deep tendon reflex of patella (L2–L4 spinal nerves and femoral nerve) and Achilles (L5–S1 sacral nerves)
  - Long tract signs including clonus, Babinski to rule out myelopathy

Hip Exam

- Exam of IT band, iliopsoas tendon for pain/snapping, including range of motion of the hip and pain with resisted hip flexion (iliopsoas) and abduction (IT band) and snapping with range-of-motion maneuvers.
- Tenderness to palpation over greater trochanter indicative of trochanteric bursitis. Note that this is usually associated with tight IT bands and can be associated with patellofemoral maltracking, anterior knee pain, and pain over lateral femoral epicondyle. If tight IT bands are suspected, perform bilateral Ober test.
- FABER test: Flexion, abduction, external rotation test (FABER)
  - Examiner brings the leg into 90 degrees of flexion
  - Externally rotate and abduct the leg, so that the ipsilateral ankle rests on the knee of the contralateral leg
- Impingement test (Dynamic internal rotatory impingement test)

  - Examined hip is brought into 90 degrees of flexion or beyond and taken through adduction and internal rotation.
  - A positive result is noted with reproduction of pain.
- Dynamic external rotatory impingement test
  - Hip is brought into 90+ degrees flexion and taken through abduction and external rotation.
  - A positive result is noted with reproduction of pain.
- Diagnostic hip injection: This is a very high-yield study to determine both diagnosis of, and prognosis with operative management of hip impingement and labral tears. Kenalog and local anesthetic (we usually use 40–60 mg Kenalog plus 5 cc of 0.5 or 0.25% maracine) are injected at the time of the arthrogram. The patient is requested to keep a pain journal for 6–8 wks after the injection and this is reviewed with the patient in clinic. The hip physical exam is also repeated before and after the injection and exam findings, especially impingement exam, are noted before and after the injection.

IMAGING

Plain Films

First, make sure that the pelvis x-ray is adequate and both iliac spines are of equal prominence; also note coccyx relationship to pubic symphesis with symmetric appearance of obturator foramina. Examine for calcified labrum, acetabular and femoral neck cysts, joint-line narrowing (early degenerative joint disease).

- Ski slope deformity (femoral neck protrudes out at the level of the head and neck junction instead of scalloping in with a convex instead of concave lateral femoral neck); this is also known as a CAM deformity.
- Crossover sign (indicates pincer deformity)
  - Found on an AP pelvis x-ray, when the line of the anterior aspect of the rim crosses the line of the posterior aspect of the rim before reaching the lateral aspect of the sourcil.

- Indicates that the acetabulum is retroverted and there is potential for pincer-type impingement.
- Most common radiographic finding is combined pincer and cam or combined impingement.

- Lateral center-edge angles (LCAs) also for pincer deformity:
  - Determines the degree of acetabular coverage of the femoral head.
  - The lateral center edge angle is measured between two lines both originating at the center of the femoral head. The first line is parallel to the longitudinal axis of the pelvis (vertical line) and the second passes through the edge of the acetabulum.
  - Normal values range from 22–42 degrees in adults.

MR Arthrogram

MR arthrograms of the hip will help in the evaluation of intra-articular pathology of the hip, particularly in finding acetabular labral tears. MRIs also help identify acetabular retroversion and articular cartilage lesions.

- MR arthrogram is examined for evidence of osteonecrosis, femoral neck stress fractures, femoral neck fractures, cartilage defects or overall chondromalacia, iliopsoas and IT band tendinitis, trochanteric bursitis, transient osteoporosis of the hip, loose bodies, labral tears. Coronals, axial, and sagittal cuts are all examined.
- Along with diagnostic hip injection and pain journal, MR arthrogram findings are the main indicators utilized for diagnosis and prognosis with surgical intervention of hip impingement and labral tears.

Nonoperative Management

- NSAID
- Activity modification
- Rest
- Physical therapy for stretching in nonpainful arc, particularly of the quads and hamstrings
- Kenalog local injection under fluoroscopy

Hip Arthroscopy: Operative Indications

- Clinical, radiographic, and exam findings consistent with FAI and/or labral tear that fail conservative measures
- Intra-articular loose bodies
- Synovitis debridement
- Septic arthritis of the hip joint

Hip Arthroscopy: Operative Contraindications

- Advanced age (relative)
- Advanced arthritis
- Medical comorbidities that preclude anesthesia
- Developmental dysplasia of the hip (relative)

Hip Arthroscopy: Surgical Technique

- After induction of general anesthesia with paralysis, the patient is placed supine on a traction table against a well-padded perineal post with a pad. Hip traction is initiated and traction time is minimized as much as possible.
- After sterile prepping and draping, an anterolateral portal is established using direct fluoroscopic guidance.
- The remaining portals are established under direct arthroscopic visualization.

Portals

- Anterolateral portal
  - Using a long spinal needle, 17 gauge or larger, start at the level of the greater trochanter and aim just below labrum toward the sourcil, using fluoroscopy.
  - Inject saline to release intra-articular vacuum.
  - A Nitinol guidewire can then be passed through the needle and into

the joint.

  - An 11 blade is used to make a skin incision and a blunt dilator is used through soft tissues to joint capsule using fluoroscopy and a cannula is inserted.
  - Diagnostic arthroscopy starts with a 70-degree scope.

- Anterior portal
  - The anterior portal is at the intersection of the ASIS (vertical line) and horizontal line from the AL portal, which should place it lateral to the femoral nerve.
- Posterior portal
  - Placed on the posterior aspect of the greater trochanter, aiming for acetabulum
- Other portals are added with the neurovascular anatomy (especially superficial femoral cutaneous nerve) in mind using an outside-in technique and direct visualization to obtain optimal osteoplasty, anchor placement, and suture passing and tying angles.
- First, a limited capsulotomy is done with banana knife and/or cautery. The acetabular osteoplasty is undertaken then single-loaded labral anchors of surgeon's choice are introduced. If the labrum tears are reparable, penetrators or lasso or spinal needles are used to pass suture into or around the labrum at sight of tear and are tied arthroscopically. A microfracture is done if full-thickness cartilage lesions are present after the osteoplasty of the pincer lesion. The traction is released and the hip is positioned in relative flexion and the camera is introduced into the peripheral compartment for cam osteoplasty as indicted. This can be carried out under fluoroscopic guidance.

Postoperative Rehab and Expectations

Patient can be partial or full weight bearing with crutches at the discretion of the surgeon, and contingent on level of femoral osteoplasty. Abduction brace after hip labral repair is optional. Physical therapy is optional and includes gentle isometric strengthening and gait training if instituted.

Complications

- Injury to the lateral femoral cutaneous can occur with anterior portal placement.
- Neurapraxia of the pudendal or sciatic nerves due to excessive traction and prolonged traction (>2 hrs).
- Sciatic nerve can be injured with posterolateral portal placement.
- Iatrogenic chondral injury.

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MENISCUS TEAR AND DIAGNOSTIC KNEE ARTHROSCOPY

HASAN SYED • JAY BOUGHANEM

Introduction

Injuries to the meniscus are one of the most common presenting complaints in an orthopedic practice. The annual incidence is estimated to be 60/100,000 people with tears being 4 times more common in men. About ⅓ of meniscal injuries occur with ACL tears. The menisci of the knee play an important role in shock absorption, load transmission, joint stability, and nutrition of the articular cartilage. Meniscal tears can be both symptomatic for patients and lead to degenerative changes of the cartilage. Depending on the nature of the meniscal tear, operative intervention may be required. Tears occur secondary to hyperflexion or twisting injuries or can be degenerative in nature. Medial meniscus tears are thought to be more common than lateral meniscus tears due to less mobility and decreased excursion during knee range of motion. Lateral meniscus tears are more common with acute ACL injury. However, medial meniscus tears are more common with chronic ACL deficiency.

Meniscal tears can be classified based on location and pattern of tear. The peripheral 3 mm of the meniscus contains an active bloody supply and is termed the red–red zone. These have the best prognosis for meniscal healing after repair. The inner part of the meniscus >5 mm away from the peripheral capsular is essentially avascular and is called the white–white zone. Tears in this region have little chance to heal after meniscal repair. The intermediate zone is called the red–white zone and is 3–5 mm from the meniscus–capsule junction. Tears can be vertical, horizontal, radial, oblique, and complex/degenerative in pattern. Generally, only vertically oriented tears are amenable to repairs. Tears can also be characterized as stable or unstable. Tears that are stable when probed do not require treatment and can be observed. Conversely, unstable tears can cause mechanical symptoms and require surgical treatment.

Stability of the tear at the time of surgery can be assessed by opening or distracting the affected compartment (slight flexion and valgus for medial and figure of 4 for lateral) and suctioning the joint versus probing to assess the level of stability. A tear that is displaced into the gutter or notch is by definition an unstable tear.

Clinical History and Presentation

- Patients with acute tears will present with a history of twisting or hyperflexion events.
- In older patients, the onset of symptoms can be insidious, particularly in those who have degenerative tears.
- Patients complain of joint-line pain, locking, catching, swelling, and loss of motion especially when turning, bending down, or with pivoting activities.
- Of note, meniscus tears, and not only ligamentous insufficiency, should be on the differential diagnosis in patients presenting with chief complaints of instability.
  - This is due to unstable torn meniscus slipping in and out of position causing jerking uneven motion that, too the patient, feels like instability in the joint.

Physical Exam

- A full exam should include assessment of gate, hip exam, knee exam, as well as vascular, neurologic, and lymphatic exam of both lower extremities.
- Knee exam should include gait assessment as well as active and passive range of motion of the knee and palpation of the medial and

lateral joint lines. Meniscal tears cause tenderness along the joint line. Inspect and palpate for an effusion, which is associated with meniscus tear as well as other intra-articular pathologies.

  - Differentiate between MCL injury in which the pain is described as a vertical band medially versus arthritis and meniscus pain, which is in a medial horizontal (back to front) type projection. Moreover, meniscus pain and arthritis pain is not worse with valgus stress at 30 degrees flexion but MCL sprain pain is. Assess for opening and end point at 0-, 30-, 60-degree flexion with both varus and valgus stress.
  - Assessing range of motion is important as a displaced meniscal tear can cause a mechanical block to full extension.
- Evaluate for concomitant ligament pathology.
- **McMurray exam**
  - Knee is held by one hand, flexed to complete flexion while the foot is held by the other hand.
  - Apply a valgus stress while the other hand rotates the leg externally while extending the knee.
  - If pain or a click is felt, this is a positive McMurray test for a tear in the posterior horn of the medial meniscus.
- **Apley grind test**
  - Patient lays prone and flexes their knee to 90 degrees.
  - Tibia is compressed onto the knee joint while being externally rotated.
  - If this maneuver produces pain, this is a positive Apley test.
- **Thessaly test**

Dynamically assesses load across the knee and has the highest sensitivity and specificity for meniscal tear testing.

  - Patient stands with the affected leg in 5–20 degrees of flexion while the other leg is raised off the ground.
  - Patient rotates the affected knee and body internally and externally 3 times with flexion maintained.
  - Pain is present at the location of the suspected meniscus tear.

Imaging

X-ray

- Weight-bearing x-rays are required. Plain radiography of the knee will evaluate for bony injury and the presence of osteoarthritis and chondrocalcinosis. Joint-line narrowing and arthritis in the joint are relative contraindications to performing knee arthroscopy.

MRI

- MRI is the most sensitive and specific study to evaluate knee internal soft tissue structures including cartilage, ligament, bone bruises, and the meniscus.

Nonoperative Management

- NSAIDs
- Activity modification
- Rest
- In patients with joint-space narrowing and osteoarthritic changes, may consider judicious use of intra articular corticosteroid injections.

Operative Indications

Indications for Repair

- Traumatic tears
- Tears located within the vascular zone of the meniscus (red–red or red–white)
- Tears >1 cm in length
- Tears in which there is minimal damage to the meniscal body fragment
- Failure of conservative management
- Tears with preserved joint line and minimal cartilage loss

Indications for Partial Meniscectomy

- Flap tears
- Degenerative tears
- Horizontal cleavage tears
- Tears in the white–white avascular zone

Surgical Technique

- Patient is placed supine on the operating table.
- Based on surgeon's preferences, A thigh holder with the knee in flexion and foot of the bed down is used, or a thigh lateral post with the knee in extension.

Diagnostic Arthroscopy

Diagnostic arthroscopy is performed to evaluate the status of the meniscus.

- An anterior-inferior portal is made both lateral (AL) to the patellar tendon and medial (AM) to the tendon. The AL portal is routinely used to perform the diagnostic arthroscopy.
- An optional superolateral portal can be used for improved visualization via outflow.
  The compartments of the knee that should be inspected with the aid of a blunt probe include the following:
- Suprapatellar pouch
- Medial and lateral gutters
- Patella and trochlea noting any patellar tilt, cartilage softening and loss, osteophytes, overall geometry of the trochlea
- Intercondylar notch
- Medial femoral condyle, medial tibial plateau, and medial meniscus (anterior, middle, and posterior horn)
- Using a "figure-of-4" position (knee in varus and variable degree of flexion) the lateral compartment is examined, looking at the lateral femoral condyle, lateral tibial plateau, and meniscus (anterior,

middle, and posterior horn)

Meniscal Repair

If a repairable meniscus is found, repair can proceed with one of three techniques:

- Inside-out
- Outside-in
- All-inside technique

Inside-out Technique

- Vertical mattress suture applied through inside out technique is the the gold standard of meniscus repair.
- Regardless of the technique used to repair the meniscus, a rasp or shave should be used to abrade the area between the tear to help facilitate a healing response.

The meniscus sutures should be tensioned with the knee in full extension as tying sutures in flexion risks potential loss of extension.

- Specialized zone specific cannulas are utilized to pass braided sutures on both sides of the tear
- Sutures are subsequently tied after being retrieved from an open incision to avoid injury to saphanous nerve/vein and peroneal nerve
- For the medial meniscus, a longitudinal 3-cm incision is made at the posteromedial corner of the knee, one-third above the joint line and two-thirds inferior to the joint line. Incision is just posterior to the MCL.
- With the knee in 90 degrees of flexion, the saphenous nerve will fall posteriorly.
- Pes anserinus is retracted posteriorly to capture inside-out suture needles anterior to the medial head of the gastrocnemius and posteromedial to the joint capsule.
- For the lateral meniscus, a small longitudinal incision is made at the posterolateral part of the knee, posterior to the LCL. The incision should be center at the joint line.

- Dissection is carried down between the ITB and biceps femoris and a retractor is inserted deep to the lateral head of the gastroc, protecting the peroneal nerve.
- Sutures are then retrieved through incisions superficial to capsule and tied.

Outside-in Technique

- Outside in technique may be used preferential for anterior horn tears.
- Spinal needles are passed from the outside of the knee across the meniscal tear and sutures are shuttled in a variety of ways.
- Sutures are retrieved and tied as indicated for inside out technique above.

All-inside Repair

- An all-inside meniscal device relies on the placement of anchoring devices (knots, anchors, tags, etc.) outside of the joint capsule.
- These devices can are designed to allow tightening of the stitch after application and are preferentially used for posterior horn tears.
- In general, outside in technique is used for anterior horn tears, inside out for body tears and all inside for posterior horn tears.

Regardless of the technique used to repair the meniscus, a rasp or shave should be used to abrade the area between the tear to help facilitate a healing response. The meniscus sutures should be tensioned with the knee in full extension as tying sutures in flexion risk potential loss of extension.

Meniscectomy

The goals of a partial meniscectomy are to trim any unstable portion of the meniscus while leaving as much meniscus intact as possible. Instruments used for this include box cutters, shavers, and graspers.

Postoperative Rehab and Expectations

Weight-bearing status is at the discretion of the surgeon. Patient can be weight bearing as tolerated with knee in extension until expected biologic healing of the meniscus (8–10 wks) with passive and active assist range of motion and isometric gentle strengthening starting immediately after surgery.

Complications

- During medial meniscus repair, the infrapatellar branch of the saphenous is at risk for entrapment.
- For lateral meniscus repair, the risk of nerve injury is to the peroneal nerve.
- Arthrofibrosis
- Suture abscess

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ANTERIOR CRUCIATE LIGAMENT INJURIES

JAY BOUGHANEM • RITESH R. SHAH

Introduction—ACL Anatomy and Pathoanatomy

The ACL originates on the posteromedial aspect of lateral femoral condyle and inserts into the intercondylar eminence of the tibia coursing posterolateral to anteromedial, it comprises 2 bundles: anteromedial that is tight in flexion and posterolateral that is tight in extension. It has an average length of 40 mm and width of 10 mm. It receives innervation form tibial nerve and blood supply from the medial genicular artery. In adults, it is generally torn midsubstance or avulses off the femoral attachment.

Clinical History and Presentation

Injury is more common in female athletes. The patient usually presents with acute hemarthrosis and limited painful range of motion after a noncontact pivoting injury on a planted foot. Seventy percent of patients hear or feel a pop. Eighty percent of patients have hemarthrosis within 12 hrs after injury.

Differential Diagnosis

- Patellar dislocation—test for patellar apprehension and pain over MPFL
- Extensor mechanism rupture (quad or patellar tendon)—test for active extension and palpable gaps

- Meniscus tear—test for joint line tenderness, catching, and locking, plus hemarthrosis that is slower to develop
- MCL rupture valgus laxity at 30-degree flexion
- Medial femoral condyle tenderness

While medial meniscus tears are more common overall, acute lateral meniscus tear are more common with acute ACL rupture. Fifty percent to 60% of ACL acute tears have an associated meniscus injury.

Physical Exam

- Acutely, patients will have an effusion with limited ROM.
- Positive Lachman test–**most sensitive:** 20 degrees of knee flexion while securing femur and translating tibia anteriorly, while assessing for an endpoint (sens 85% spec 95%).
- Positive anterior drawer test: Same as Lachman but at 90 degrees of knee flexion (sens 40% spec 85%).
- Positive pivot shift—**most specific:** Knee brought from full extension to flexion while applying a valgus moment to the knee and axial load watching for tibial reduction at lateral joint line (usually better performed under anesthesia; sens 25%, spec 98%).
- Missed PCL injury is a common reason for failed ACL reconstruction. Dial test will show excessive external rotation at 30 degrees but not 90 degrees of knee flexion.

Imaging

- **X-ray**
  - Segund sign: bony margin avulsion of lateral capsule from lateral condyle, tibial eminence avulsion (more common in pediatrics)
- **MRI**
  - Complete ACL tear from femoral attachment or midsubstance best seen on sagittal T2 image
  - Empty wall sign on coronal image

- Bony contusion on lateral condyle and posterolateral tibia
- Always assess meniscus, patella, trochlea, MCL, LCL, and extensor mechanism

Prevention

Neuromuscular training including plyometrics, balance and technique training reduce ACL injury in female athletes.

Nonoperative Management

- ACL knee bracing (reduces instability events but not arthritis and meniscus tears) and WBAT
- NSAIDs
- Elevation
- Rehabilitation: range of motion, hamstring strengthening, proprioceptive training

Operative Indications

- Young, high athletic or occupational activity level
- Instability with activities of daily living
- Multiligamentous injury
- Failure of conservative management
- Positive pivot shift
- Prior to planned ACL reconstruction, patient should attain full ROM with resolution of swelling and acute inflammation

Contraindications

- Extensor mechanism insufficiency
- Limited ROM

- Advanced osteoarthritis
- Acute infection
- Noncompliance with rehab protocol

GRAFT SELECTION

- Auto BPTB, auto-quadrupled hamstring, allograft BPTB, allograft-quadrupled hamstring, allograft Calcaneal-Achilles.
- Considerations
  - Harvest site morbidity
  - Tendon strength and tendon–bone healing
  - Patient age and activity
  - Disease transmission
  - Surgeon experience
- Most important: Good surgical technique and tunnel placement

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SURGICAL TECHNIQUE

Pre-op area: Take a history and repeat physical exam in pre-op. Be aware of anesthesia plan, antibiotics. Obtain consent and mark operative site.

Positioning: Supine, tourniquet ±. Options included circumferential leg holder versus lateral post.

Exam under anesthesia: Confirm pivot shift, anterior drawer, and Lachman tests prior to prep and drape.

Diagnostic arthroscopy: Routine knee arthroscopy confirming ACL rupture, particular attention to rule out meniscus tears (see chapter on meniscectomy for details).

Notchplasty: Perform a thorough notchplasty, visualizing past residents' ridge to view the posterior capsule and be able to hook a probe on the posterior wall of the lateral condyle.

- Perform a thorough ACL debridement: note relationship of ACL tibial insertion (footprint), PCL/ACL interface, and posterior aspect of anterior horn of lateral meniscus.

Graft Harvesting

For Hamstring

- Palpate semitendinosus and gracilus medially
- Make skin incision slightly posterior to midway between anterior border and medial border of tibia
- Cut sartorius longitudinally, palpate at each level
- Cut and tag gracilus and semitendinosus and use closed or open harvester to follow and obtain grafts
- Release of bands under visualization and palpation to follow tendon path are key to avoid premature graft cuts

For BTB

- Make incision anterior over patellar tendon
- The skin incision can be shorter than the actual tendon length and is used with flexion and extension window to see proximal and distal bonecuts
- Cut paratenon
- Identify middle third of tendon and cut with knife
- Mark and cut with saw bone plugs 1 cm wide and 1–2 cm long at each end
- Use saw and osteotome to release the bone plugs
- Make cuts in V shape to help dissociate graft from donor bone

Graft preparation: At the back table (assuming BPTB allograft). Femoral bone plug usually 9–11 mm circumference and 9–10 mm length. Tibial bone plug 8–10 mm circumference and 8–10 mm length. Make sure that tendinous length is appropriate for patient height. Insert double sutures at each end through drill holes.

Tibial tunnel placement: Place intra-articular portion of ACL tibial guide with following landmarks in mind: center the tunnel at the native ACL footprint, at posterior aspect of anterior horn of lateral meniscus with the center of the tunnel 8 mm anterior to PCL (most consistent landmark). Then, attach the drill guide usually at 55 degrees angle and start reaming at mid aspect of medial tibial crest and tibial tubercle.

Femoral tunnel placement: With the knee flexed, using the anteromedial portal, tibial tunnel, or an accessory portal between those two, insert the over-the-top guide into the notch, so that its posterior lip hugs the posterior cortex and is between 10:00 o'clock and 11:00 o'clock for right (1:00 and 2:00 for left). This will typically give 2 mm of intact posterior wall. Insert guide and then drill with appropriate length and width to accommodate bone plug. This step will change based on choice of femoral fixation. Confirm intact posterior wall with probe after drilling.

A retrograde reamer with an outside in guidewire that transforms to flip cutter and retrograde reamer can provide for anatomical femoral tunnel placement without accessory AM portal or requirement for high flexion needed for transtibial portal placement.

Passing the graft: Dilators can be used at surgeon's discretion. The beath pin used as a guide for the femoral tunnel drilling will have a pin hole at its end in which the sutures, secured to the graft can be pulled. A femoral bone plug size 1 mm smaller than the tibial plug will facilitate this step.

Securing the graft: Multiple methods are available and highly surgeon dependent. Cortical fixation with ENDO BUTTON or similar type device is the strongest. Interference screws are very common. Notching the tunnel and screw conversion help achieve better fixation and avoid bone plug rotation. The graft is typically tensioned at the back table. After securing the femoral plug, tension the graft with multiple flexion/extension cycles before securing the tibial plug.

Final steps: Take arthroscopic images with the graft in place. Cycle the joint with the scope in place to exclude graft impingement. Wash the joint and close the incision and portals. A negative pivot shift after reconstruction is the most specific predictor for return to play of division 1 athletes. Apply a knee immobilizer and may allow full weight bearing in extension. Chemoprophylaxis is dealer's choice but lethal PEs after ACL recon have been reported.

Postoperative Rehab and Expectations

Weight bearing as tolerated immediately postoperatively in full extension

Rehabilitation bracing versus functional bracing versus no brace: Decreased swelling, wound drainage, and pain in acute setting with brace. No difference at 2 yrs.

Continuous passive motion machine: No difference

Focus on Hamstring strengthening. No open chain active quads in early rehab as it will stress the graft. Max stress on graft is with terminal 30-degree or resisted open chain extension. Straight leg raises are encouraged, however.

Nonaccelerated program (accelerated program): discontinue brace at 4 wks (2 wks), open kinetic chain exercises with quadriceps contraction at 12 wks (4 wks), return to preinjury activity at 32 wks (24 wks).

Most important: Explain to the patient that the rehab is long and difficult. Stress the importance of compliance with restrictions to obtain the most successful result.

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POSTERIOR CRUCIATE LIGAMENT INJURIES

HASAN SYED • JAY BOUGHANEM

Introduction

The posterior cruciate ligament is the main posterior stabilizer of the knee. Although not as commonly injured as the anterior cruciate ligament, PCL injuries occur in 3–30% of all acute knee injuries. The incidence is higher in those involved in a motor vehicle accident or high-speed trauma. It is 1.5 times larger in cross-sectional area compared to the ACL. The PCL has its origins on the lateral border of the medial femoral condyle and attaches on the posterior tibia between the medial and lateral tibial plateaus, 1 cm distal to the joint line. The tibial insertion is located just anterior to the popliteal neurovascular bundle.

It is important to evaluate the posterior lateral corner (PLC) in patients suspected of having PCL injuries since up to 60% of patients will have associated PLC injuries.

Clinical History and Presentation

- PCL injuries most commonly occur through a direct blow to the proximal tibia. They are particularly associated with motor vehicle accidents where the proximal tibia strikes the dashboard.
- In sports, PCL injuries occur with hyperflexion due to falls onto a flexed knee with the foot and plantar flexion. Patients will often present within large effusion after an acute PCL injury.
- In any multiligament knee injury or knee dislocation, PCL injury in addition to neurovascular injury should be highly suspected in the

presence of an effusion.

Differential Diagnosis

Isolated PCL injury, PCL and PLC injuries, PCL and PLC and ACL injuries, knee dislocation, personal nerve injury, chronic and acute PCL injuries

Physical Exam

- When PCL injuries are suspected, the noninjured knee should first be examined to determine the proper relationship of the tibia to the femur. Posterior subluxation can then be corrected before assessing anterior displacement. Otherwise, in a PCL-deficient knee, the clinician may determine an ACL deficiency when in fact the patient may have a PCL tear or both.
- **Posterior drawer test**—most sensitive to determine PCL deficiency.
  - Performed with the knee held in 90 degrees of flexion.
  - Once proper tibial femoral relationship is established, a **posteriorly** directed force is applied.
  - Grading of injury
    - Grade 1: Posterior translation = 1–5 mm
    - Grade 2: Posterior translation = 5–10 mm
    - Grade 3: Posterior translation $>$10 mm
- **Posterior SAG test**
  - Performed with the knee and hip flexed to 90 degrees and patient in the supine position; both the legs are held in the air.
  - Compared with the uninjured knee, the tibia in the PCL-injured knee subluxes.
- **Quadriceps active test**
  - Patient, laying supine with knees flexed to 90 degrees, contracts quadriceps muscle and with quadriceps contraction, the PCL-deficient knee will reduce to proper position.

Imaging

X-ray

- Plain radiography of the knee will evaluate for bone avulsion off the posterior tibia, indicating avulsion of the tibial insertion.
- Stress radiographs with posterior drawer force will indicate posterior displacement.

MRI

- Knee MRI is the most sensitive and specific study evaluating PCL injuries.

Nonoperative Management

- Generally, isolated grade 1 and 2 PCL injuries can initially be treated nonoperatively. Measures include protected weight bearing and focus on quadriceps muscle strengthening.
- Return to play may be within 4 wks after full range of motion is obtained with equivalent muscle strength to contralateral side. For grade 3 injuries, the knee is splinted in extension for 2–4 wks.
- Immobilization in extension decreases tension on the PCL and also prevents posterior subluxation.
- Patients with grade 3 injuries with persistent instability after 8–12 wks, especially those with medial or patellofemoral symptoms, may be surgical candidates.

Operative Indications

Indications for Repair

- Acute isolated grade 3 PCL injuries
- Persistent instability despite 4 wks of treatment in full extension
- In multiligament knee injuries, PCL reconstruction is recommended within 2–4 wks, with repair of collateral structures, posterolateral corner, and, if needed, ACL reconstruction

- Chronic grade 3 PCL injuries require surgery if there is persistent instability and pain

Surgical Options

- Multiple variations of posterior cruciate ligament reconstruction have been described. Techniques include single bundle, double bundle, open versus arthroscopic, and inlay versus arthroscopic tunnel techniques.
- Biomechanical studies have examined single versus double bundle posterior cruciate ligament reconstruction. Stability was increased with double bundle reconstruction and there was better restoration of rotational stability than single bundle technique. Clinical studies to show superiority of double versus single bundle are lacking. However, technically, double bundle reconstructions are much more demanding than single bundle techniques.
- Open inlay techniques involve placement of the tibial fixation of the PCL with the bone plug portion of the graft. This requires a posterior approach to the knee and prone position.
  - The single biggest advantage of an open inlay technique is that it avoids the acute angle created with the tibial tunnel position of a conventional trance tibial tunnel. With the traditional tunnel, there is an ~72–90° angle (killer angle) to traverse. This creates a sharp edge around which the graft can elongate over time and makes passing the graft technically more difficult.
  - The typical graft used with open inlay is an Achilles tendon allograft.
- For single bundle reconstruction, bone patellar tendon bone or Achilles graft can be used. Soft tissue allografts are used routinely for double bundle PCL reconstructions.

Complications

- **Most critical complication to avoid** in PCL reconstruction is inadvertent injury to the popliteal neurovascular structures during tibial tunnel placement.

- Improper placement of tunnels.
- Graft attenuation, particularly around the two corners the tibial tunnel-first corner as the tunnel exits the posterior tibia midline and the second corner between the posterior tibia and tibial plateau.

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LATERAL COLLATERAL LIGAMENT AND POSTEROLATERAL CORNER INJURIES

HASAN SYED

Introduction

Injuries to the posterolateral corner (PLC) of the knee occur both in isolation and with concomitant multiligament knee trauma. If neglected, severe PLC injuries can lead to chronic disability from persistent instability and cartilage wear. PLC-isolated injuries represent $<2\%$ of all acute ligament knee injuries but may be present in 30–60% of multiligament knee trauma. Early diagnosis may allow for primary repair and better prognosis instead of reconstruction at a later date thus making initial recognition critical for these injuries.

A number of structures make up the PLC of the knee. Although there has been confusion both with regard to the anatomy and terminology, the PLC can be best described by five key structures and a number of supporting structures. The key components of the PLC are the popliteus tendon, the lateral collateral ligament (LCL), popliteal fibular ligament, lateral head of the gastrocnemius, and the arcuate complex. The biceps femoris tendon and iliotibial band are key contributing structures to the stability of the posterolateral side of the knee and are often damaged with injuries to the lateral side of the knee.

Biomechanically, the PLC serves as the main restraint to external rotation and varus forces. The LCL is the most important varus restraint while the remaining components play a key role in resisting external rotation. After the posterior cruciate ligament, the PLC serves as the next most important restraint to preventing posterior translation of the tibia on the femur.

Clinical History and Presentation

- Mechanisms commonly associated with PLC injuries include direct trauma to the proximal medial side of the tibia, resulting in hyperextension, noncontact hyperextension external rotation with twisting of the knee, direct trauma to the flexed knee, or any high-energy trauma to the knee resulting in fractures.
- A high index of suspicion should be present with any injuries resulting in peroneal nerve dysfunction and resulting foot drop.
- As with all multiligament knee injuries, a diligent vascular exam needs to be performed since popliteal vessel damage can be present.

Physical Exam

The uninjured knee needs to be examined just as carefully as the affected knee when assessing for PLC and LCL injuries.

- LCL injuries are best assessed with varus stress with the knee in 0 and 30 degrees of flexion, with tibia held in neutral rotation.
- The laxity and end point exams are compared to the uninjured side.
- Varus instability at 0 degrees indicates a much more severe injury pattern.
- Laxity is graded based on side-to-side laxity.

  Three types of exams may be considered.

Dial Test

- Most commonly employed exam for the PLC assessment
- Place patient either in a supine or prone position
  - Prone positioning can result in a better side-to-side assessment
- Use one hand to maintain proper reduction of the tibia while the

other hand holds the patient's foot with external rotation forces at both 30 and 90 degrees of knee flexion

- At 30 degrees of knee flexion, more than a 10-degree difference between the affected and the unaffected side indicate insufficiency of the PLC
- If there is increased external rotation at 90 degrees of knee flexion as well, a PLC and PCL injury are suspected

Posterolateral Drawer Test

- Flex patient's knee to 80 degrees
- Externally rotate the foot while applying a posterior load to the knee itself
- Test is positive when the tibial plateau rotates posteriorly and externally, relative to the medial tibial plateau

Reverse Pivot Shift Test

- Bring knee from 90 degrees of flexion into full extension
- Place valgus load and apply a simultaneous external rotation maneuver via the foot
- The test is positive when the posteriorly subluxed lateral tibial plateau dramatically reduces at 30 degrees of flexion, due to the iliotibial band becoming a knee extensor
- Positive exam indicates chronic posterolateral insufficiency

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Imaging

MRI

- MRI of the knee is the most **sensitive** and **specific** study evaluating LCL and PLC injuries.

X-ray

- Varus stress radiographs of the knee will reveal lateral-sided opening.

Classification

Injuries are classified based on rotational and varus instability:

- **Grade** 1 injuries
  - Minimal instability
  - <5 mm of varus and 5 degrees of external rotation difference
- **Grade 2** injuries
  - $=$ 5 to 10 mm of varus instability and 5–10 degrees of rotational stability
- **Grade 3** injuries (severe)
  - >10 mm of varus stability and/or 10 degrees of rotational stability

Nonoperative Management

Isolated LCL and PLC injuries of grade 1 and 2 severity are best managed nonoperatively.

- Extension immobilization followed by progressive range of motion, strengthening, and progressive weight bearing; with expected full return of activity expected at 3–4 mos postinjury.
- Assess patients with grade 3 LCL injuries based on their activity levels, as there will be residual laxity and potential poor outcomes with nonoperative management.

Surgical Options

Acute grade 3 PLC injuries are best treated within 1 wk of the trauma to achieve better surgical identification of the various PLC structural components.

- Acute treatment makes direct repair with or without augmentation possible.
- Direct repair improves chances for native anatomic restoration and normal biomechanics.
- After 3 wks, acute repairs become increasingly difficult.

Principles of acute PLC repair include the following:

- Proper open exposure of injured structures
- Identification and protection of the peroneal nerve
- Addressing any associated knee fractures
- Addressing avulsion of the structures with direct fixation with suture anchors, or other fixation methods.
- Midsubstance tears can be repaired primarily; however, midsubstance repairs of the LCL are best treated with augmentation.
  - Augmentation consists of simple single bundle reconstruction of the LCL and/or popliteal tendons, and repair of the midsubstance tear of the LCL to the reconstructed ligament.

Chronic injuries (or acute injuries where PLC structures are not identifiable), require reconstruction.

- After 4–6 wks, capsular scarring and contraction make it nearly impossible to visualize and localize structures for repair.
- Important to identify any lower limb malalignment in chronic instability.
  - Varus thrust can result in a higher rate of failure of the reconstruction if not addressed with an osteotomy procedure.
- Although reconstruction is preferred over nonsurgical treatment in the setting of significant instability, there is no standard reconstruction procedure for the PLC.
- Reconstructions can be divided into fibula-based versus tibia–fibular-based procedures.

Examples

- **Larson reconstruction** consists of a fibular tunnel through which a ligament is brought posteromedially and exits anterolaterally and is fixed at single lateral epicondyle origin site.
- **LaPrade PLC reconstruction** is more involved, requiring two separate ligaments, tunnels in the tibia, fibula, and two tunnels for fixation for the popliteal and LCL origins.
  - This reconstruction also recreates the popliteofibular ligament.
  - Biomechanically, the LaPrade reconstruction allows for near-

anatomic restoration of external rotation and varus stability.

Remaining **non-PLC ligament injuries** can be treated primarily or staged based on patient status, surgeon preference, and the consideration for potential risk of arthrofibrosis.

Complications

- Peroneal nerve injuries occur in up to 20% of cases of PLC-associated trauma
- Iatrogenic injury to the peroneal nerve can occur during repair as well as during reconstruction, particularly with tunnel placement
- Postoperative compartment syndrome
- Fibular fracture from tunnel placement
- Residual laxity, with secondary patellofemoral arthritis and subsequent medial and lateral tibiofemoral arthritis
- Arthrofibrosis

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MULTILIGAMENTOUS KNEE INJURIES AND KNEE DISLOCATIONS

HASAN BAYDOUN

Introduction—Knee Ligaments

There are four major ligamentous stabilizers of the knee: ACL, PCL, MCL, and PLC. Relevant anatomy is discussed separately in the corresponding chapter on injuries to each.

Clinical History and Presentation

Knee dislocations are typically the result of high-energy trauma. For knee dislocations to occur, 3 of the 4 ligamentous are disrupted.

- Most common dislocation involves both cruciates, and medial and/or lateral ligamentous complexes.
- Other associated injuries include fractures, but more importantly, injuries to vasculature and neurologic structures around the knee.
- Controversy surrounds the exact management of a knee dislocation, and this relates to the rare incidence, and lack of evidence thereof, to support proposed treatment algorithms.

Physical Exam

Physical exam involves assessing each of the ligaments separately (might be difficult due to pain).

- All patients with suspected knee dislocations must be admitted for **24-hr observations**.
- Serial **neurovascular** checks initiated in the ED.
- All patients require an **ABI** on admission.
  - If ABI <0.9, or different than contralateral uninjured limb, patients will require angiography (gold standard to evaluate for vascular status).
- Frequent neurochecks required, with evaluation for impending **compartment syndrome** due to the high-energy nature of the injury.
- Initial evaluation should include assessment for **open wounds**.
- Physical exam should be repeated in the operating room with the patient under anesthesia if any surgical intervention is planned.

Imaging

- **X-ray**
  - Evaluate for associated signs of ligaments (e.g., Segund, Pellegrini–Stieda, etc.).
  - More importantly, evaluate the direction of dislocation, adequate reduction, and associated fractures.
- **US**
  - ABI with Doppler on BLE
- **MRI**
  - Evaluate for ligamentous injury (see relevant chapters).

Nonoperative Management

Historically, knee dislocations were managed nonoperatively. Currently, unless otherwise indicated, knee dislocations are stabilized acutely, and then managed operatively.

In the setting of periarticular fracture associated with ligamentous knee injury, allow fractures to heal before pursuing ligamentous reconstruction.

Operative Indications

- Analysis on patients treated operatively showed that they had higher functional scores, and better motion than those treated nonoperatively.
- All patients with knee dislocations should be considered for surgery; however, controversy still surrounds the timing of surgery.
- If patient requires vascular reconstruction, has an unstable reduction or an open wound, external fixator should be applied to ensure stability for the vascular repair.
  - External fixator is removed at the time of definitive surgery.
- Assess ligamentous stability BEFORE applying fixator, as you should not stress the knee in the presence of a vascular repair.
- For PLC injuries, both repair and reconstruction are acceptable options and approach depends on time of surgery and other patient factors.
- Although isolated MCL injuries are approached non operatively, there may be a role for primary MCL repair in cases of knee dislocation and multiligamentous knee injury.

Surgical Approach and Graft Selection

- ACL/PCL typically are reconstructed arthroscopically and PLC/MCL approached open.
- Timing of reconstruction, acute versus chronic, remains controversial, and no studies conclusively show superiority of one opposed to the other.
- For PCL, consider allograft due to increased volume of soft tissue.
- For ACL, consider bony fixation for the femoral side (Achilles or patellar tendon).
- MCL and PLC graft choices are controversial.

Surgical Technique

Staging surgery: The goal of staging surgery is to perform reconstruction in a timely manner, yet allowing for inflammation of surrounding soft tissue envelope to subside. Stiffness is encountered at a lower incidence if reconstruction is performed earlier (≤6 wks). If bicruciate and medial side reconstruction, allow for 6 wks in hinged knee brace because MCL can heal under adequate tensioning, obviating the need for surgical repair or reconstruction.

Pre-op area: Take a history and repeat physical exam in pre-op. Be aware of anesthesia plan, antibiotics. Obtain consent and mark operative site. Depending on surgeon preference, may forego choice of surgical block, as it may hinder exam in the postoperative period.

Positioning: Supine, tourniquet ±. Options included circumferential leg holder versus lateral post.

Exam under anesthesia: Confirm pivot shift, anterior drawer, Lachman, posterior drawer, varus thrust, and all corresponding stability maneuvers prior to prep and drape.

Diagnostic arthroscopy: Routine knee arthroscopy confirming ligamentous injury, and particular attention to rule out meniscus tears (see chapter on meniscectomy for details).

Surgical technique: Depending on affected ligamentous structures involved, will require reconstruction in a sequential manner. Most important is to anchor the PCL in position. After securing the PCL graft, this will act as a reference point to secure all other grafts in a position.

Final steps: After securing the grafts in position. Cycle the joint with the scope in place to assure nonimpingement. Wash the joint and close the incision and portals. A negative pivot shift after reconstruction is the most specific predictor for return to play of division 1 athletes. Apply a knee immobilizer and may allow full weight bearing in extension.

Postoperative Rehab and Expectations

Weight-bearing status: Will depend on the ligaments reconstructed, and the respective type of graft/fixation used. Typically, patients are allowed PWB in the immediate post-op period, and then allowed to progress to WBAT at the 6-wk post-op mark.

Bracing: All patients require a hinged knee brace, in the immediate postoperative period. Brace is worn for six or more weeks post operatively.

Continuous passive motion machine: No evidence of difference in clinical outcomes at 1 yr after reconstruction.

Range of motion: Patients allowed passive range of motion from 0–90 degrees immediately, and encouraged to ambulate PWB. Respective graft stresses and protection depending on the patient, and ligaments reconstructed. Most patients are progressed out of brace and into WBAT at 6 wks.

Points to stress to patient: Long and protracted course. Initial injury is very traumatic, and cartilage damage present at time of initial injury may result in post traumatic arthritis. Results with multiligamentous injuries and knee dislocations are guarded relative to single ligament reconstruction. Patient should be instructed that further surgery may be required in the future including but not limited to revision surgery and/or partial or total knee arthroplasty.

Most important: Explain to the patient that the rehab is long and difficult. Return to sport is seldom at a competitive level. The prognosis is guarded, especially when compared to single-ligament injuries of the knee.

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PATELLOFEMORAL JOINT

JAY BOUGHANEM

Introduction

Anterior knee pain is a very common reason for patient presentation to an outpatient orthopedic clinic. The term anterior knee pain syndrome or patellofemoral syndrome is an umbrella diagnosis, the differential diagnosis for which includes anterior knee pain due to patellar maltracking and tilt, lateral patellar instability, patellar chondromalacia, patella-femoral arthritis, quadriceps and patellar tendinitis, medial plica syndrome, fat pad syndrome, runners knee or IT band irritation over the lateral femoral epicondyle, and pes anserine bursitis. Obtaining a detailed history and performing an appropriate exam is key to the diagnosis and treatment.

It is critical to determine whether the patient's patellofemoral complaints are primary or secondary. Primary patellofemoral complaints can be caused by increased activity level, tight IT band, injury, or fall. Secondary patellofemoral complaints can be associated with any internal knee injury or pathology including meniscus tear, ligament tear, and cartilage injury.

Clinical History and Presentation

- Patients with patellofemoral syndrome or pain due to patellar maltracking often present with discomfort with walking up or downstairs as well as
  - sitting down from standing
  - standing up from seated position
  - squatting

- walking up or down inclines
- pain after prolonged sitting or prolonged steady knee flexion.

- A history of sudden increase in activity or exercise frequency can sometimes be elicited.
- Patients may not have pain with walking on flat ground.

Physical Exam

- Gait is examined first with attention to patellar position and tracking.
- Hip exam is conducted with range of motion including internal and external rotation.
- Excessive femoral anteversion and hip internal rotation is associated with patellofemoral pain.
- IT band is examined by checking for tenderness over the posterior greater trochanter and lateral femoral epicondyle. Concomitant IT band tightness and patellofemoral maltracking are often present. The patient is questioned for the location of the pain. Ober test is performed and both sides are compared to assess for IT band tightness.
- The quadriceps are examined and compared to evaluate for atrophy.
- The knee is inspected for surgical scars. Careful palpation of the quadriceps tendon, patellar tendon, lateral femoral epicondyle, and lateral retinaculum is conducted.
  - Tenderness over the lateral and medial patella-femoral joint line is checked and noted.
  - Patellar lateral and medial mobility is checked and apprehension with lateral traction in extension is checked.
  - A lateral location of the tibial tubercle and high Q angle is noted.
- Active and passive range of motion is checked with attention to crepitus with range of motion. Pain with resisted knee extension at low and high angle of knee flexion is checked as well.
- Several factors can be associated with patellofemoral pain syndrome.

Larger patellar tilt angle, trochlear sulcus angle, Q-angle, quad atrophy and weakness, hip abduction, extension, and external rotation atrophy and weakness are all factors that are more often present in patients with PFS compared to control, and should be examined during patient evaluation.

Imaging

X-ray

Plain x-rays of the knee including AP, lateral, Rosenberg, and sunrise are checked.

- Lateral views are evaluated carefully to check for shallow or convex trochlea and for effusion.
- Sunrise view is checked for tilt and osteophytes. Any joint-line narrowing, cysts, sclerosis, or osteophytes are noted.

MRI

- For acute injury or history suspicious for lateral subluxation or dislocation, the medial retinaculum and MPFL are checked for signal indicating injury and the lateral femoral epicondyle may have characteristic traumatic contusion.
- Axial cuts are carefully evaluated for tilt and cartilage loss. Bone signal in the patella on T2 weighted images or equivalent, is associated with chondromalacia and arthritis.

Nonoperative Management

- Conservative management comprises oral anti-inflammatory medications, activity modification, and therapy including home exercise, supervised therapy, or formal physical therapy.
- Therapeutic modalities should be based on careful exam and identification of pathologies present.
  - Focus on quadriceps in general with a focus on vastus medialis oblique strengthening is often warranted.

- May include open-chain exercises such as straight leg raises with or without weights in neutral and external rotation, as well as closed-chain exercise like wall sits.
- Therapy should also focus on stretching the IT bands. In some patients, hip external rotator and hip extensors strengthening are helpful.

- Involving the patient in their therapy with home teaching and home exercises is key to success with therapy. Patients' noncompliance with home exercises is the main reason for conservative management failure.

Operative Indications

Surgery may be indicated for patients who have refractory symptoms despite conservative management. The surgical procedure is contingent on the pathology present.

- Arthroscopic or open lateral release is considered for patellar tilt.
- Patient with high Q angle and recurrent instability may benefit from tibial tubercle transfer, medial patellofemoral ligament reconstruction versus VMO advancement with lateral release.
- Concomitant cartilage loss may benefit from cartilage-specific procedures like microfracture, OA TS, autologous cartilage implantation, facetectomy, or partial patellectomy can be considered.
- Patellofemoral replacement or total knee replacement is considered for patients with end-stage arthritis in the patellofemoral joint.

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EARLY ARTHRITIS IN ATHLETES AND YOUNG PATIENTS

JAY BOUGHANEM

Introduction

Patients with knee degenerative joint disease, who have life expectancy greater than the life expectancy of modern total joints, who have activity demands that are expected to cause increased joint wear, or have high work demands may require different management compared to physiologically older patients with lower level demands.

The main principles in managing young patients with cartilage loss or early arthritis are to appropriately manage the patient's expectations; attempt to restore the mechanical axis and stability of the joint if the joint is out of alignment, or is unstable; and address the cartilage defect present based on size and location.

Clinical History and Presentation

- Patients may present with pain at rest, activity-related pain, or instability. They may also describe joint crepitus, popping, catching, giving out, swelling or loss of range of motion, and strength.
- The pain is usually centered over the joint line—more commonly, over the medial joint line versus the lateral joint line.
- **Tibiofemoral pain** is worse with weight bearing and with walking on flat ground. In contrast, **patellofemoral pain** is worse with stairs, walking up and down inclines, standing from seated, sitting from standing, and after prolonged sitting.
- Prior joint trauma with meniscus and ligament injury is not

uncommon. Furthermore, patients may have prior interventions, open or arthroscopic including meniscus-, ligament-, or cartilage-directed procedure.

- The impact of the symptoms on the patient life is usually very significant with inability to work or participate in sports or desired recreational activities secondary to pain and disability.
- Questioning the patient regarding their previous activity level, work, and sport participation is important. Furthermore, discussing the natural history of arthritis and anticipated outcome with and without treatment and the probability or requiring further future interventions helps set appropriate expectations.
- It is important to note findings related to patellofemoral symptoms (pain with stairs, standing from seated, sitting from standing, etc.) on history because the exam for patellofemoral pain may not be very specific.

Physical Exam

Patient evaluation should include exam of the patient's overall appearance and body habitus, gait, lumbar spine, hip, and knee with comparison to the contralateral side when abnormal findings are encountered.

- The patient's gait should be observed for shortened stance, stiff knee gait, varus or valgus thrust, malalignment. Moreover, difficulty with standing from seated position or sitting from standing should be noted.
- The examiner should check for pain with straight leg raise, with lower back lateral bending and extension, as well as distal motor, sensation and reflexes to rule out concomitant lower back pathology.
- Hip exam should follow with hip log roll and range of motion.
- Active and passive range of motion of the knee is checked and compared to the other side.
  - Flexion and extension contractures are noted. The knee is inspected for surgical scars, muscle atrophy, and effusion.

- The location of the tibial tubercle in relationship to the midpatella and Q angle is noted.
- The joint is palpated for effusion, medial, lateral, and patellofemoral joint line tenderness. Any tenderness over the patellar tendon, quadriceps tendon, medial and lateral retinaculum is noted.
- Careful exam for instability including varus and valgus stress at 30 degrees for the collaterals, posterior and anterior drawer, and Lachman are done with comparison to the other side. Crepitus over the tibiofemoral joint or patellafemoral joint may indicate kissing cartilage lesions.
- The exam for patellofemoral pathology is not specific and the diagnosis is easier to establish based on the patient's history. However, pain with active knee extension against resistance, at different degrees of flexion may indicate patellofemoral pathology. Joint line tenderness, although a sensitive test for cartilage loss/arthritis and meniscus tears, is not specific for either pathology.

Imaging

X-ray

- Hip to ankle standing weight-bearing bone length views are critical and indispensible in evaluating a young patient with suspected arthritis. Any deviation of the mechanical axis from neutral on these x rays should be noted and compared to the other side. Restoration of a close to neutral axis is one of the treatment goals.
- Standard knee x-rays including AP, PA in 30-degree flexion, lateral, and sunrise are reviewed. The AP and PA views need to be obtained with the patient standing. Non–weight-bearing x-rays will miss joint line narrowing.

MRI

- Cartilage lesions are demonstrated on MRI in two ways: directly and indirectly.
  - **Indirectly:** Cartilage loss will cause increase in bone stress and this

can be easily seen as edema and intraosseous fluid signal on T2 sequences or equivalent. This can be easily recognized even if the MRI scan is of lower resolution or smaller magnet.

  - **Directly:** Cartilage loss can be a cartilage-deficient lesion that is fluid filled over the articular surface on T1 or T2 sequences.
  - **Correlating the direct and indirect findings** will increase the accuracy of the read.
- If the physician does not have access to a high-resolution/high-power magnet, **MR arthrogram** may be helpful in getting a more accurate read. This is also helpful in patients who had prior knee surgery.

CT

- If an MRI is contraindicated due to pacemaker or any other reasons, a **CT arthrogram** can be used to evaluate the meniscus and cartilage. This study will show defects in cartilage but will not show secondary edema.

Nonoperative Management

Conservative management in patients with cartilage loss should focus on weight loss when appropriate, activity modification, pain control, restoration of the knee joint range of motion, and reversing muscle atrophy. Braces may be considered but there is no strong supporting evidence for their use. Steroid-based injections to a joint with healthy cartilage globally but with a limited defect should be used judiciously and local anesthetics avoided.

- Patients can be advised to avoid impact exercises. Alternatives to running can be presented. Cardiovascular exercises that do not involve joint impact that can be suggested include walking, swimming, using stationary bike or a rowing machine.
- Oral nonsteroidal anti-inflammatory medications, acetaminophen, COX-2 inhibitors can be used for pain control.
  - Oral medications should be used judiciously as these problems can be very long-term issues and oral medications can have deleterious effects on the liver and the kidney. Patients should be

    warned regarding the negative side effects of long-term use of these medications and over-the-counter pain medications.
  - Using narcotic pain medication should be discouraged if possible.
- If flexion or extension contractures are present, physical and home therapy should be used to attempt to restore a full joint range of motion. This is of particular importance if surgical interventions are planned. The physician should consider delaying surgery until range of motion is optimized through physical and home therapy.
- Strengthening should focus on core, hip and knee strengthening.
  - Knee strengthening should include quadriceps and hamstring exercises. Progress with therapy can be followed by measuring quadriceps circumference 2–4 cm above the superior pole of the patella.
  - Strengthening exercises may include straight leg raises, single- and double-legged wall sits, and prone hamstring curls.
- Secondary patellofemoral pain can be present in the knee regardless of the primary etiology of the patient's symptoms. This can be due to overall decompensation, quadriceps atrophy, and IT band tightness.
  - The examiner may have difficulty defining the primary versus secondary cause. Physical therapy and home therapy should encompass appropriate patellofemoral rehabilitation to include quadriceps/vastus medialis strengthening, IT band stretching, and hip external rotators and extensor strengthening.
- The AAOS guidelines for knee arthritis suggest regular patient follow-up, weight loss, activity modification, low impact and range-of-motion exercise, quadriceps strengthening, and patellar taping; advise against shoe wedges, and could not recommend for or against unloader braces.

Operative Indications

The two main indications for surgery in patients with cartilage loss are to address symptoms in patients who have failed conservative management and to attempt to hold back further deterioration of the joint. Surgery in asymptomatic patients should be approached with extreme care and avoided if possible.

- The first goal of surgery is to restore neutral alignment with neutral tibiofemoral mechanical joint axis and normal patellofemoral tracking. In contrast to older patients – in whom the goal of coronal plain osteotomies may be to overload the unaffected compartment – in the young patient, a neutral mechanical axis equivalent to the unaffected side in cases of unilateral involvement is sought.
- Correction in the coronal plain includes medial opening wedge high tibial osteotomy for varus deformity and opening wedge distal femoral osteotomy for valgus deformity.
- Tibial tubercle transfer combined with lateral release and medial VMO advancement or medial patellofemoral ligament reconstruction is used when patellofemoral tracking is abnormal.
- Cartilage defects are addressed based on size and location. In the tibiofemoral joint, microfracture or osteochondral autograft transplantation (autograft OATS) can be considered for small lesions (<2–$4\ cm^2$). Autologous chondrocyte implantation (ACI) or osteochondral allograft transplantation (allograft OATS) are considered for larger lesions.
- In the patellofemoral joint, the prognosis for cartilage defects is more guarded. Autologous cartilage transplantation is an off-label use for patellar defects but some recent studies show relatively high success rates when patellar maltracking is corrected.
- The surgical plan should include correction of the mechanical alignment or maltracking if present primarily, and the cartilage defect secondarily.

Surgical Technique

High Tibial Osteotomy

- Patient is positioned supine on a radiolucent table in anticipation of utilizing intraoperative fluoroscopy. A bump is used under the hip to get neutral rotation of the lower extremity with the patella facing straight up. A tourniquet is applied over the proximal thigh and the extremity is exsanguinated. A far posteromedial or a straight anterior incision can be used.

- The periosteum is encountered and is cut and elevated proximal to the tibial tubercle. The periosteum is elevated all the way posteriorly and a retractor is positioned over the posterior tibia to protect the neurovascular bundle.
- A guidewire is placed under fluoroscopic guidance starting at a level just proximal to the patellar ligament insertion on the tibial tubercle and directed toward metaphyseal cancellous bone at the level of the styloid of the fibular head started distal and medial, and progressing in an oblique, proximal and lateral direction.
- The patellar ligament is protected. An oscillating saw is used to make a cut over the guidewire staying 1 cm medial to the lateral cortex.
- The lateral cortex is left intact. A wide straight osteotome is used to slightly open the osteotomy followed by progressively large wedge-shaped bone temps and a laminar spreader.
- Two laminar spreaders can be used to gradually open the osteotomy allowing to place the fixation plate of choice midcoronal to posterior.
- An alignment rod or the Bovie cord is positioned at the center of the femoral head and the center of the talus and observed over the knee to confirm a neutral mechanical axis.
- A plate is chosen that matches the required opening and applied. Two cancellous screws are applied proximally and two cortical screws are placed distally. Bone graft is used to fill up the defect. A staple is used laterally if breach of the lateral cortex is encountered.
- Passive range of motion is started immediately postoperatively and a hinged knee brace is used with protected weight bearing until the osteotomy heals.

Distal Femoral Osteotomy

- Positioning is carried out as described for high tibial osteotomy. An anterior or far lateral incision can be used. IT band can be split or cut. The vastus can be split in line or elevated of the intermuscular septum and retracted anteriorly.

- Periosteal dissection is carried out posteriorly with the knee in flexion and a Homan retractor is placed behind the femur.
- A guidewire is placed starting at the most proximal aspect of the metaphyseal flare laterally and is driven from a proximal lateral in a distal medial direction toward cancellous bone just distal to the end of the flare.
- An oscillating saw is used to make a partial cut distal to the wire and the medial cortex is left intact. The osteotomy is then opened gradually with osteotome and wedge-shaped bone temps. Two laminar spreaders can be used to get stable gradual controlled opening.
- An appropriately sized fixation plate of choice is applied between the laminar spreaders after fluoroscopic confirmation of 0-degree mechanical axis. Fixation is accomplished with 2 distal cancellous screws and 2 proximal cortical screws. The defect is filled with bone graft.
- Postoperative instructions are similar to high tibial osteotomy.

Tibial Tubercle Transfer with Lateral Release and Vastus Medialis Advancement

Lateral Release

- Lateral release is indicated for isolated tilt. Tibial tubercle transfer is indicated for translation.
- Same positioning and setup described above is utilized. An anterior knee incision is utilized. The quadriceps tendon, patellar ligament, vastus medialis, and vastus lateralis are identified.
- The lateral release detaches patella from lateral soft tissue structures. These include the IT band and lateral retinaculum. The joint capsule can be left intact. Care is taken to preserve vascular structures.
- The lateral patellofemoral and patellotibial ligament are confluences of the lateral retinaculum and are released along with the lateral retinaculum.

Vastus Advancement

- A medial parapatellar arthrotomy is carried with a cuff of tissue left intact over the medial patella.

- When closing, the medial tissue cuff attached to the patella is closed over the medial retinacular tissue attached to the vastus in a "pants over vest" fashion to elevate the patella with the vastus advanced to the midpole of the patella.

Tibial Tubercle Transfer

- The periosteum is incised over the medial and lateral aspect of the patellar tendon and tibial tubercle and distal to the tubercle. The periosteum is elevated more in a posterior and lateral direction to the level of the posterior lateral corner of the tibia. A distal hinge is left intact.
- An oscillating saw is used to make 4 cuts.
  - A transverse cut is made at the level of the patellar tendon insertion on the tibial tubercle.
  - A sagittal cut is carried out medially straight posterior just medial to the tubercle.
  - Laterally, a long oblique cut and a short oblique countercut are made intersecting farther away from the lateral border of the tubercle and toward the posterior lateral border of the tibia.
  - With the distal aspect left intact, the cuts are finished with an osteotome and the tubercle with a long bone bridge distal to it are mobilized both medial and anterior.
  - Two 3.5-mm screws are used to fix the osteotomy at its new location. The medial overhang is excised and used as bone graft. Additional demineralized bone matrix allograft can be used to fill the lateral defect.
  - The patient is kept toe-touch weight bearing until the osteotomy heals.

Microfracture

- Microfracture which can be done arthroscopically, is appropriate for smaller defects (2–4 cm^2) and is believed to be more successful when carried on the femoral condyle compare to tibial plateau and patella.
- The borders of grade three and grade four lesions are identified. A Curette or ring curette can be used to define the borders of the

defect and create a cylindrical gap with vertical shoulders surrounding the gap. A curette is used to remove the calcified cartilage layer at the floor of the defect.

- A Steadman awl or 2-mm drill bit can be used to drill the bone bed. The awl should penetrate the subchondral bone in a vertical fashion.
- The microfractures are created 5 mm apart and should be at least 5 mm deep. Putting the microfractures too close together risks making an unstable fracture.
- The tourniquet is released to demonstrate bleeding from microfracture or drill sites and if blood does not come out, the microfracture or drill hole can be carried deeper.
- The patient is kept toe touch or nonweight bearing for 6 wks and a continuous range of motion machine is used for 6 wks, 6 hrs a day.

Autologous Chondrocyte Implantation

- ACI may be appropriate for larger defects ($>$2–4 cm^2). Cells are harvested arthroscopically from the nonweight bearing area over the medial or lateral aspect of the femoral notch. The cells are harvested and packaged and sent to a lab where they are cultured and the multiplied cartilage cells are then sent back for implantation.
- The implantation requires either a medial or lateral parapatellar arthrotomy contingent on the site of the defect. The borders of grade three and grade four lesions are identified. A Curette or ring curette can be used to define the borders of the defect and create a cylindrical gap with vertical shoulders surrounding the gap.
- A curette is used to remove the calcified cartilage layer at the floor of the defect. A layer of periosteum harvested from the proximal tibia or an artificial membrane can be sutured circumferentially to create a water-tight–covered cylindrical gap. The membrane is first sutured and then glued except at the intended site of insertion of the cell colloid. The cells are injected and final suture and glue is applied.
- Postoperative management is similar to microfracture.

Autograft OAT

- Autograft OAT, like microfracture, may be appropriate for smaller defects (< 2–4 cm^2). The procedure can be carried out open or arthroscopic. Accessory portals including transpatellar tendon portals may be required.
- If arthroscopic technique is intended the knee is stabilized at the optimal level of flexion and a spinal needle is used to localize the optimal location of the accessory portal that will provide vertical approach to the donor cartilage.
- Grafts are collected, based on the size of the defect from non–weight-bearing cartilage. Donor sites include:
  - far medial trochlea
  - inferior medial and inferior lateral femoral intercondylar notch
  - sulcus terminalis or junction of weight-bearing distal femoral condyle
  - non–weight-bearing trochlear cartilage
- Grafts are usually 5 mm in diameter and 15 mm deep. The harvest sites are kept 2 mm apart.
- The recipient site is prepared. A spinal needle and varying angles of knee flexion or extension are used to determine the optimal arthroscopic portal incision. A coring reamer is used to prepare the recipient site, which is drilled 2–3 mm deeper than the plug acquired from the donor site. The plugs are gently and atraumatically impacted in place.
- Patients are kept nonweight bearing or toe-touch weight bearing for 6–8 wks. Passive range of motion is started immediately.

Allograft OAT

- Allograft OAT, like ACI, may be appropriate for larger defects (> 2–4 cm^2).
- A size- and side-matched condyle is required. This is usually nonirradiated freeze dried. The procedure can be carried out open or arthroscopic. Since this procedure is done for larger defects, it is more likely that a peripatellar arthrotomy or mini arthrotomy is required.

- The recipient site can be prepared first utilizing an appropriately sized coring reamer. The site can be covered with one large plug or multiple small plugs.
- Donor grafts are collected, based on the size of the defect from corresponding site of the defect in the recipient.
- Failure is due to failure of bone in the allograft as the bone part of the graft is required to incorporate by creeping substitution for successful surgery. The technique should attempt to utilize allograft donor plugs that have minimum bone thickness.
- The plugs are gently and atraumatically impacted in place.
- Patients are kept nonweight bearing or toe-touch weight bearing for 6–8 wks. Passive range of motion is started immediately.

Postoperative Rehab and Expectations

Depends on operative procedure utilized.

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PATELLAR LIGAMENT AND QUADRICEPS TENDON INJURIES

JAY BOUGHANEM

Introduction

Extensor mechanism traumatic disruption can occur at the level of the quadriceps tendon, patella, or patellar ligament. Quadriceps tendon ruptures occur more commonly in patients >40 yrs with medical comorbidities while patellar ligament ruptures occur more commonly in patients who are <40 yrs. History and clinical exam are the main method to diagnose these entities while plain films and MRI can play a confirmatory role.

Clinical History and Presentation

- Patients with **quadriceps tendon rupture** present with sudden onset of pain associated with eccentric loading of the quadriceps with knee effusion and inability to walk or extend the knee. It is more common in males in their 50s or 60s with medical comorbidities including gout, renal disease, diabetes, or hyperthyroidism.
- Patients **with patellar ligament rupture** present with sudden onset of pain with knee effusion and difficulty with walking and knee extension as well. Quadriceps tendon rupture occurs in a more extended position compared to patellar ligament rupture where the knee is in a relatively more flexed position.

Physical Exam

- The patient will have difficulty with standing or bearing weight on the affected extremity. On inspection there will be effusion in the affected joint. In complete rupture, the patient will be unable to actively extend the knee or hold the knee extended against gravity. The patella will have more side-to-side mobility on the affected side.
- On inspection and palpation, the patient will have a lower patella on the affected side with quadriceps tendon rupture. The patient will have a higher patella on the affected side with patellar ligament rupture. A palpable defect is present over the quadriceps or the patellar ligament.

Imaging

X-ray

- Plain films will show patella infra with quadriceps tendon rupture and patella alta with patellar ligament rupture. This is more notable on lateral views.
- Moreover, the plain films can be examined for effusion as well as continuity of the patellar ligament and quadriceps tendon on lateral views.

MRI

- Useful to confirm finding on history and exam but not required prior to surgery. Also useful in patients who are not compliant with the exam or in which the diagnosis is equivocal on clinical evaluation alone.

Nonoperative Management and Surgical Indications

- Surgery is indicated in patients with complete traumatic loss of the extensor mechanism to restore premorbid function. Conservative management is only indicated in patients with incomplete rupture. The ability to extend the knee or hold the extended knee against resistance is what differentiates complete from incomplete rupture.
- Conservative management comprises preserving knee extension until

healing. This can be accomplished via using a well-padded trochanter to malleolus cast versus knee immobilizer for 6 wks. Patient can be weight bearing as tolerated as long as knee extension is maintained. Formal physical or instructions for home therapy are instituted to restore strength and range of motion.

Surgical Technique

- Technique is similar for quadriceps tendon and patellar ligament rupture; and it is contingent on whether the disruption is tendon to bone or ligament to bone versus soft tissue based.
- The patient is positioned supine with a bump under the hip joint.
- A longitudinal incision over the midsagittal plane of the knee is used. Dissection is carried down to expose the defect in the extensor mechanism and the retinaculum.
- No. 2 fiber wire or no. 5 Ethabond nonabsorbable suture is typically used.
  - **Soft tissue–bone disruption** is repaired by 2 Krakow stitches (4 limbs) that are passed over 3 bone tunnels and tied.
  - **Soft tissue–based disruption** is fixed with 2 Krakow stitches that are tied end to end.
- The strength of the repair is contingent on the number of strands passing the gap. The repair is examined for any gap at the conclusion of the repair.

Postoperative Rehab and Expectations

- Postoperative management is similar to conservative management described for incomplete disruptions.

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OSTEOCHONDRITIS DISSECANS OF THE KNEE

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Introduction

The etiology of Osteochondritis Dissecans (OCD) is a subject of debate and is probably multifactorial. It has been suggested that these lesions, like stress fractures, are caused by repetitive stress or trauma, namely from the impingement of the medial tibial spine over the PCL origin area of the medial femoral condyle. Other theories suggest a vascular watershed area as well aberrancies in epiphyseal ossification.

OCD is most common in the knee but also occur in the talus and capitellum among other locations. The prognosis of OCD is related to the patient's skeletal maturity as well as the location of the OCD in the knee. The lateral aspect of the medial femoral condyle is the most common location. OCD in the patella is extremely rare.

Patients with OCD with open physis and typical lateral aspect of medial femoral condyle location who have a stable-appearing lesion on MRI have better prognosis.

Clinical History and Presentation

- The classic patient with OCD of the knee is a young skeletally immature male. The patient symptoms at presentation will be contingent on the stage of the OCD.
- Early lesions with cartilage softening may present with vague knee pain and intermittent swelling. Pain could be worse with activity including weight bearing, walking, and running. Patients with detached lesions, however, may complain of mechanical symptoms

like locking, popping, catching, or giving out.

Differential Diagnosis

Cartilage injury, early arthritis, inflammatory arthritis, ligament or meniscus injury, loose bodies.

Physical Exam

- A standard orthopedic and knee exam is conducted. Gait is examined first.
  - A particular gait pattern observed in patients with medial femoral condyle OCD.
  - This pattern includes increased tibial external rotation angle and subsequently increased foot progression angle to relieve the impingement of the medial tibial spine on the lateral aspect of the medial femoral condyle
  - This could be associated with antalgic gait
- Hip exam is conducted with range of motion, impingement testing, and pain with logrolls. Hip pathology should always be in the differential diagnosis when examining the knee, especially in adolescents.
- Knee exam should include active and passive range of motion and muscle strength testing.
  - Any crepitus, locking, popping, catching with passive range of motion is noted.
  - The joint is inspected for quad atrophy, effusion, or surgical scars. It should be palpated for effusion, joint line tenderness, and tenderness in the tibiofemoral and patellofemoral joints; as well as tenderness over the patellar tendon, quadriceps tendon, medial and lateral retinaculum.
  - Patellofemoral stability and tracking is examined. Overall stability is examined as well.
- It should be noted that patellofemoral syndrome and anterior knee

pain may be present as a secondary finding. This could be related to disuse atrophy in the VMO and quadriceps that is precipitated by the primary pathology.

- The **Wilson test** may be specific for typical OCD lesions.
  - To perform the test, the knee is flexed to 90 degrees; tibia is internally rotated and the knee is gradually extended.
  - Pain at 30 degrees of flexion that is relieved with external rotation may be specific to tibial spine impingement on the lateral aspect of the medial tibial femoral condyle-–the location of the typical OCD lesion.

Imaging

X-ray

- Standard knee plain radiographs including weight-bearing AP, weight-bearing PA with 30° flexion, lateral, and skyline views are ordered and reviewed.
- It is not uncommon to miss OCD lesions on plain radiographs. **A high suspicion of OCD warrants adding a notch view.** The patient lays prone with knee flexed 40° and the x-ray beam is angled 40° caudad.

MRI

- An MRI is useful to better classify the lesion and to rule out any associated pathology.
- The MRI will establish the exact location and size of the lesion. More importantly, will elucidate whether the lesion is stable, unstable, or detached. A surrounding rim of fluid around the OCD signals an unstable lesion.

Classification

There are many classification schemes for OCD of the knee. Unfortunately, like many other areas of orthopedics, classification is not management- or prognosis-oriented.

An easy way to classify OCD lesions in the knee is to describe the following:

- 1. Are the physes open?
- 2. Is the location typical or atypical?
- 3. Is the lesion stable, unstable, or detached?

Nonoperative Management

- Conservative management includes activity modification, bracing or casting, protected weight bearing, oral anti-inflammatory medications, as well as home and formal physical therapy. Skeletally immature patients with a stable typical location OCD lesion will have excellent prognosis with conservative management.
- There is no high level evidence that indicates the superiority of one conservative management methodology versus another. The main principle in management of the patient conservatively, however, is to attempt to unload the stress on the OCD lesion. Activity modification and refraining from impact exercises is required. A cast in 30–40° of knee flexion is useful in patients when compliance is in doubt.
- Physical therapy is indicated to restore range of motion loss and reverse any secondary muscle atrophy.

Operative Indications

Surgery is indicated for unstable lesions, detached lesions, and stable lesions that have failed conservative management.

Surgical Technique

Surgical management utilized will be contingent on the stage of the OCD lesion. **Stable lesions** can be treated with drilling. Drilling can be carried out arthroscopically in transarticular or retroarticular fashion.

Arthroscopic Retroarticular Drilling

- A diagnostic knee arthroscopy is carried out. The OCD lesion is identified via direct visualization and fluoroscopy.
- A 2-mm guidewire is inserted percutaneously from the metaphysis into the center of the lesion and the position of the guidewire is confirmed via fluoroscopy with 2 orthogonal views.
- A second guidewire is similarly inserted in the periphery of the lesion. With those 2 guidewires defining the lesion location, multiple passes with a 2-mm drill bit are carried out.
- Unstable lesion management is contingent on the quality and state of the OCD lesion itself.
  - If the lesion has sufficient bone, it can be debrided along with the donor site and fixed utilizing metallic or bioabsorbable compression screws.
  - A medial or lateral parapatellar arthrotomy can be utilized to gain access.
  - If the lesion is fragmented or does not have a sufficient bone composition, it should be removed and treated as described for detached lesions.
- Detached OCD lesions are treated with excision of the loose body and will require assessing and addressing the donor site, which can be treated with microfracture, ACI, autograft or allograft, OAT as described elsewhere in this section.

Postoperative Rehab and Expectations

Main principle in rehabilitation is to protect weight bearing if an unstable lesion was fixed or microfracture technique was utilized and to start early passive range of motion to avoid stiffness.

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SHOULDER IMPINGEMENT AND DIAGNOSTIC SHOULDER ARTHROSCOPY

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Introduction

Shoulder impingement is a very common cause of shoulder pain and comprises a spectrum of shoulder problems ranging from subacromial bursitis to rotator cuff tendinitis, partial and full-thickness rotator cuff tears and rotator cuff arthropathy. The early theory regarding shoulder impingement is the extrinsic theory propagated initially by Codman in the early 1900s and adopted and expanded by the writings of Neer and Bigliani. This theory proposes that impingement occurs between the anterior/anterolateral acromion and the greater tuberosity causing compression on the anterior cuff. This extrinsic mechanical compression causes inflammation in the cuff and bursa as well as cuff tears. Neer classified impingement into three stages. The first is subacromial and bursal inflammation and hemorrhage. The second is cuff tendinitis and cuff partial tears. The third is full-thickness cuff tears. Bigliani categorized acromial morphology based on outlet shoulder views into type I flat acromion, type II curved, and type III hooked acromion.

The intrinsic theory advocates that cuff pathology is more biology based and not related to extrinsic compression and mechanical failure. It is argued that most partial cuff tears are articular not bursal, hence mechanical compression cannot be the sole reason they occur. It is argued that a hypovascular watershed area exists in the anterior cuff, which explains the reason cuff tear most commonly occur in the anterior fibers of supraspinatus.

The actual cause for impingement and cuff tears is probably a combination of extrinsic and intrinsic factors.

History/Presentation

- Patients with shoulder impingement commonly present with insidious onset shoulder pain that is more commonly localized over the lateral deltoid and is exacerbated by overhead activity.
  - On history, the patient typically deny pain or discomfort with activities that do not require shoulder abduction/forward flexion, or with activities performed with the elbow at the side.
  - The patient may also complain of night pain that may or may not wake the patient up from sleep.
  - Patients often complain of difficulty with sleep on the affected shoulder.
  - Rest pain is unlikely with impingement and may indicate arthritis or adhesive capsulitis.
  - Mechanical symptoms including locking, catching, and giving out are more suggestive of labrum/superior labrum pathology and are less likely to occur with impingement and cuff tears. However, superior labral lesions and biceps anchor pathologies can occur concomitantly with impingement and cuff tears.
- Conversely, a patient may present with acute worsening of shoulder pain as well as new onset of weakness superimposed on chronic shoulder discomfort with overhead activity. This may suggest an acute or subacute cuff tear, which may benefit from early surgical intervention.
  - Attritional cuff tears are more common in the older population and up to 30% of patients >60 yrs may have cuff tears. Asymptomatic cuff tears in the contralateral shoulder are also more common in older patients.
  - Acute cuff tear patients usually present with acute onset of shoulder pain and or weakness after acute trauma. Acute cuff tears, according to the AAOS rotator cuff guidelines may benefit from early surgical intervention and should be evaluated accordingly.

- Older patients who sustain a shoulder dislocation, although are less likely to sustain recurrent dislocations, are more likely to sustain concomitant traumatic cuff tears and should be evaluated and managed accordingly.
- If pain persists after successful reduction and appropriate conservative management of a shoulder dislocation, further workup with an MRI is warranted.
- Personal or family history of autoimmune disease (Lupus, RA, etc.) should raise suspicion for adhesive capsulitis.
- Complaints of activity independent day rest pain is more consistent with adhesive capsulitis and glenohumeral arthritis.

Physical Exam

Gaining proficiency in doing a thorough, and consistent shoulder exam can be facilitated by organizing it into distinct structures or pathologies. This will provide a plan and a systemic thought process when evaluating the patient. A cervical spine exam should be an integral and indispensible part of every shoulder exam. One suggested variation is to divide the exam into the following sections and to consistently follow the same order with every patient:

1. Cervical Spine Exam (ROM, long tract signs, gate, bilateral upper extremity sensation and strength, spurling)
2. Active and passive range of motion of the shoulder
3. Inspection (may include evaluation for cuff atrophy, AC prominence, surgical scars, asymmetry)
4. Impingement exam (Neer, Hawkins, Active Range of motion)
5. Strength and Cuff Exam (Empty can, Drop Arm, External rotation lag, abduction strength, lift off and belly press, external rotation with adduction)
6. AC joint exam to assess sprain, instability, arthritis of the AC joint (tenderness to palpation, cross body adduction, prominence)
7. SLAP Exam (Obrien's)
8. Biceps exam (tenderness to palpation anteriorly with arm

internally rotated 10–20 degrees, Speed, Yergeson)

9. Glenohumeral Joint (arthritis with anterior and posterior joint-line tenderness, crepitus with glenohumeral motion, rotator cuff arthropathy with pseudoparalysis, anterosuperior escape)
10. Instability with apprehension, relocation, load shift, drawer, sulcus, sulcus with external rotation

A diagnostic local anesthetic injection to the subacromial space can also aid in the exam. This is especially useful in patients with pain related to multiple etiologies, had prior shoulder surgery, or have atypical findings that make the diagnosis more challenging. It can also differentiate between weakness due to structural defect in patients with cuff tears and weakness due to inflammation and impingement. Testing for passive range of motion if active range of motion deficit is present is critical in differentiating between impingement/cuff tear versus adhesive capsulitis. Loss of passive range of motion is the hallmark finding in patients with adhesive capsulitis.

Imaging

- The shoulder plain films should include a true anterior–posterior view of the shoulder, an axillary view, a scapular Y view; and a practitioner may consider an outlet view as well. A shoulder series is incomplete and unacceptable without a proper axillary view.
- The anteroposterior view can be used to evaluate for calcific tendinitis, glenohumeral joint space narrowing, cysts, or osteophytes, proximal migration of the humeral head (normal acromiohumeral distance is 7 mm), AC joint arthrosis, inferior osteophytes, or instability. Osteophytes inferior to the AC joint may precipitate or exacerbate shoulder impingement.
- The scapular Y and axillary view can be used to evaluate for glenohumeral instability, glenoid bone loss, and bony Bankart lesions.
- The outlet view can be used to evaluate acromial morphology (type 2 or 3 acromion) and inferior AC joint osteophytes, conditions that predispose to impingement. Moreover sclerosis of the anterolateral acromion and sclerosis and degenerative cysts of the greater

tuberosity should be noted as possible indications of impingement.

- The treating orthopedic surgeon should evaluate every shoulder series, and if an independent radiology report is generated, it should be reviewed as well and compared to the read. Incomplete series and inadequate projections should be repeated.
- MRI, MRI arthrogram, CT, and CT arthrogram can be used to evaluate the shoulder further. Shoulder cuff atrophy or fatty infiltrations should be evaluated first; this can be done using T1 or equivalent MRI or CT scan sagittal cuts. T2 coronal and sagittal cuts can be used to evaluate the supraspinatus and infraspinatus for tear location and size. Axial cuts can be used to evaluate the biceps tendon and the subscapularis as well as posterior cuff and glenoid cartilage loss and version. Labral tears are easier to see on MR arthrograms but can be often adequately viewed on plain MRI. Whether to get MR arthrogram for labral tears continues to be a subject of debate.
- The treating practitioner/orthopedic surgeon should personally review all 3D imaging. If independent reports are generated by the radiologist, those should be reviewed as well but should support not replace the treating orthopedic surgeon's own evaluation.
- The MR magnet and software utilized can affect the quality of the imaging obtained. Usually, a 0.7-T magnet is insufficient and 1.5-T magnet or better is required to get adequate visualization of the soft tissues and cartilage. Open MRI magnets commonly provide image quality inferior to closed magnets.

Conservative Treatment

- Patients with shoulder impingement or rotator cuff–related symptoms without evidence of full-thickness cuff tear or acute cuff tear are initially treated nonsurgically using activity modification, formal or home-based physical therapy, local steroid injection, and/or oral nonsteroidal anti-inflammatory medications.
  - Naproxen sodium or Ibuprofen can be used. In the absence of renal insufficiency or intolerance, naproxen is easier to use with a 500 mg PO BID formulation.

- If the patient is unable to tolerate NSAIDS, and do not have history of cardiac disease or sulfa allergy, Celebrex 100 mg PO QD or BID can be used. Physical therapy can be initiated with focus to decrease inflammation, establish normal range of motion, and promote scapular stabilization, proper mechanics, periscapular, deltoid and cuff strengthening.
- Home teaching and promoting patient independence in doing home exercises is critical. Joint mobilization may include inferior, anterior, and posterior scapular plane glides.

- Local cortisone injections should be used judiciously for inflammation and pain control. However, these injections can be a great asset in the diagnostically challenging patient and in patients with concomitant shoulder and cervical spine pathology.

Operative Indications

- Arthroscopic or open surgical intervention is indicated in symptomatic patients with full-thickness rotator cuff tears and in patients with partial rotator cuff tear and/or shoulder impingement who fail appropriate conservative management.
- Rotator cuff repair is indicated if 50% of the cuff or 0.7 mm of the footprint is exposed, otherwise rotator cuff debridement is an acceptable alternative.
- Subacromial decompression according to the AAOS practice guidelines is not routinely required when rotator cuff repair is done. The recommendations are based on level II evidence in cohorts that underwent rotator cuff repair. However, soft tissues and bony decompression greatly aids in visualization during cuff repair.

Surgical Technique

Diagnostic Shoulder Arthroscopy, Subacromial Decompression with Coplanar Resection of the AC Joint.

- General anesthesia with or without scalene block is used.
- The patient is positioned in a beach chair position or lateral decubitus depending on the surgeon's experience and training.
  - For beach chair positioning, there are multiple commercially available table extensions to aid in positioning including the Tenent/Smith and Nephew beach chair table extension.
  - An electric or pneumatic arm-holding device (e.g., spider arm holder) can be used intraoperatively as well.
  - Care is taken to position the cervical spine in neutral flexion and rotation. The shoulder and entire upper extremity should be prepped and draped. Shoulder landmarks including acromion, clavicle, and coracoid are drawn.
- Prior to surgery, an exam under anesthesia is performed to evaluate for passive range of motion and any instability.
- Both shoulders are examined and compared. A gentle manipulation under anesthesia to obtain full range of motion is carried out when indicated. A standard posterior portal is made 1 cm inferior and 2 cm medial to the posterior-lateral acromial edge.
- Before inserting the scope obturator, the joint can be insufflated with 40 cc of normal saline to ensure atraumatic entry to the glenohumeral joint.
  - Either outside-in or inside-out technique can be used to establish an anterior portal.
  - The joint should be examined systemically in a methodical and ordered standard manner. This should include evaluation of the cartilage and bone, labrum circumferentially, posterior cuff, infraspinatus and bare area, supraspinatus, and subscapularis.
  - The biceps should be pulled into the joint and inspected. The superior and anterior labrum should be inspected and probed.
  - The glenohumeral ligaments should be carefully inspected.
  - Positioning the shoulder in 20 degrees of abduction, external rotation and forward flexion will aid in visualizing the anterior

    cuff and evaluate for the presence of high-grade partial or full-thickness tears without retraction.

  - If there is doubt regarding the size of the tear, a localizing PDS or nylon suture can be passed into the tear for later visualization from the bursal side.
  - The shoulder can be inspected from both posterior and anterior portals.

- The same posterior skin incision is used to gain access to the subacromial space.
  - A standard lateral portal can be used for instrumentation.
  - Most beginner arthroscopists position the lateral portal close to the acromion edge making the resection unduly difficult.
  - A good rule of thumb is to position the lateral portal mid acromion and the same acromial width (lateral acromion to post AC joint) distal or lateral.
  - First step in subacromial arthroscopy is to visualize the coracoacromial ligament and the bony anterolateral edge of the acromion.
    - A subtotal bursectomy can be carried out with combination of motorized shaver and cautery.
    - A spinal needle inserted outside in to the anterolateral tip can help with orientation if in doubt.
    - The CA ligament can be recessed or resected. 0.7–1 cm of acromion is resected from anterolateral to AC joint medially to the midcoronal plane posteriorly. The goal of the subacromial resection is to obtain a flat acromial morphology or type I acromion.
    - Both the posterior and lateral portal should be used for visualization to ensure adequate resection.
  - A subtotal bursectomy can be carried out with combination of motorized shaver and cautery.
    - In case of inferior AC joint osteophytes, either a coplanar resection of the AC joint or coplanar resection and distal clavicle excision can be carried out.

- The bony subacromial resection can be started with the scope in the posterior portal and a 0.5-mm barrel burr in the lateral portal with initial focus on the anterior and anterolateral resection to a point medial to lateral clavicle; or in other words, medial to the AC joint.
- Inserting the scope laterally and the burr from the posterior portal can finish the resection. The posterior acromion is used as a reference and guide to obtain flat acromial morphology with this technique.

- Postoperative rehabilitation is contingent on the final procedure done.
  - In the case of diagnostic arthroscopy and decompression, physical therapy should be started immediately focusing on range-of-motion and strengthening exercises.
  - A shoulder sling is optional for comfort but not required. Follow-up is scheduled for wound check 7–10 d postoperatively. DVT prophylaxis is with early mobilization and aspirin can be added.

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ROTATOR CUFF TEARS

JAY BOUGHANEM

Introduction

Rotator cuff tears can be subdivided into acute or traumatic cuff tears and chronic or attritional cuff tears. The distinction between acute traumatic and chronic tears is important because it may dictate management and a carefully obtained patient history is critical for this evaluation. Rotator cuff tears can also be anatomically categorized into posterior-superior tears that commonly involve infraspinatus and supraspinatus and superior-anterior tears, which involve supraspinatus and subscapularis. This distinction is important because it affects the operative management plan as the order of tendon repair can influence the ease of surgical repair.

History/Presentation

- Patients with rotator cuff tears and shoulder impingement present with similar complaints.
  - They commonly complain of pain over the lateral deltoid.
  - However, they may complain of anterior or posterior shoulder pain as well.
  - Any pain that radiates beyond the elbow is not shoulder related but more likely brachial plexus or cervical spine related.
  - However, concomitant shoulder and cervical spine problems are not uncommon and can be interrelated as cervical spine pathology may precipitate shoulder muscle atrophy, abnormal mechanics, and pain. Moreover shoulder pathology and restricted glenohumeral motion can precipitate in pathologic scapular over

compensation, which can cause neck discomfort and pain.

  - Patients with rotator cuff tears commonly have pain with overhead activity while activities below 30 degrees of shoulder abduction/flexion are pain free.
  - Rest pain is uncommon with rotator cuff tears and impingement but more common with adhesive capsulitis and glenohumeral arthritis; however, night pain that awakens the patient from sleep is very common.
  - Shoulder weakness can be due to rotator cuff tear or due to pain.
  - Shoulder stiffness and secondary adhesive capsulitis can be present at variable degrees.
    - The first motion lost is most commonly internal rotation
    - Female patients can have difficulty with buttoning or unbuttoning their bras
    - Male and female patients may complain of difficulty placing or retrieving objects from their back pockets.
- It is critical to try to establish whether the tear is chronic/attritional or acute traumatic during the patient interview.
  - The patient should be questioned regarding any trauma that may have precipitated the symptoms.
  - This should be correlated with atrophy on exam and MR imaging.
  - The patient should also be questioned regarding any history of shoulder dislocations as those can correlate with acute cuff tears.

Physical Exam

- The exam of the shoulder should be performed systemically in a thoughtful and organized fashion: It should start by examining the cervical spine; then examining the shoulder; testing for active and passive range of motion; assessing shoulder impingement, rotator cuff muscle strength, and utilizing special tests.
  - The **cervical spine exam** should include the following elements: range of motion, Spurling test, strength and sensory testing, reflexes, and long tract signs and Hoffman.

    - Active range of motion: Any asymmetry in bending or rotation is noted.
    - Spurling exam: Assess for nerve root impingement:
        - This involves C spine extension along with bending to the ipsilateral side and gentle axial compression.
        - Reproduction of any concordant chief complaint with Spurling is noted.
    - Muscle testing based on nerve root can be carried out next.
        - Abduction can be used to test for C5, resisted elbow flexion and wrist extension for C6, resisted elbow extension and wrist flexion for C7, finger flexion for C8, and finger abduction for T1.
        - Sensory distribution is assessed as well, any sensory loss over C5 (lateral shoulder), C6 (thumb), C7 (middle finger), C8 (little finger), or T1 (axillary areas) is noted.
        - Reflex testing is useful if asymmetric hyper reflexes are present.
        - Hoffman, Clonus, and Babinski should be done if the prior exam or history indicates cervical spine involvement/possible myelopathy.
- The second step in the shoulder exam is careful **shoulder inspection**.
    - Hence, the patient should be gowned appropriately for this step to allow visualization of both shoulders for comparison.
    - The inspection should be done from behind and in front to evaluate for supraspinatus/infraspinatus atrophy, anterior-superior escape, AC joint prominence, surgical scars, deltoid atrophy, pectoralis asymmetry and this step is continued throughout the range-of-motion evaluation.
- The third step is to evaluate active and passive **range of motion**
    - This should include abduction, forward flexion, external rotation with and without abduction, and internal rotation.
    - The easiest and best way to evaluate internal rotation is by comparing how high can the patient scratch their back with the arm adducted and internally rotated noting the highest position

of the tip of the thumb on both sides.

  - Discrepancy or internal rotation loss can be assessed by how many spinal segments are lost between sides.
  - If a marked active rotation deficit is involved, the exam should proceed with measuring passive range of motion as well.
  - Any significant loss of passive range of motion should raise suspicion of adhesive capsulitis.
- Evaluation for **impingement** should include the Neer, Hawkins, and painful arc of motion.
  - For the Neer sign, the examiner stabilizes the scapula and passively brings the arm into forward flexion/forward flexion and internal rotation if pain is elicited at 80–90 degrees of forward flexion, a "Neer sign" is present.
  - If pain is diminished after a local anesthetic is injected into the subacromial space, then it is positive "Neer test."
  - Hawkins test is described as passive abduction in the plane of the scapula with internal rotation.
  - A positive arc of motion is present when shoulder pain is elicited with active range of motion 60 and 120 degrees of active motion.
  - A variation of this test that I use in my clinic that is not formally reported but pending publication is comparing painful active arc of motion between external rotation and internal rotation. In this variation, the patient is asked to actively abduct the arms in the plane of the scapula with the thumbs pointing to the ceiling then with the thumbs pointing to the ground.
  - Worsening pain with active range of motion with internal rotation with the thumbs pointing to the ground indicates a positive test. The difference in the level of abduction required to illicit pain comparing abduction with internal rotation versus abduction with external rotation may correlate with the amount of inflammation/pathology present.
- To assess the **rotator cuff muscle strength**, drop arm and external rotation lag, resisted abduction in the plane of the scapula, resisted external rotation with the elbow at the side, lift off and belly press tests are done.

- Weakness in resisted arm abduction and external rotation is noted.
  - This can be due to structural reason or due to pain.
- Repeat exam after subacromial local injection can differentiate the two.
- Inability to hold the arm in abduction without pain may indicate a supraspinatus tear.
- A positive lag sign is present if the patient is unable to hold the arm in external rotation after the examiner passively positions the arm in maximum external rotation with the elbow at the side.
  - This indicates posterior cuff defect, including infraspinatus tear.
- Lift off test is resisted internal rotation with the arm in adduction and internal rotation off the lumbar spine.
  - Belly press is done with the elbow to the side and assess upper subscapularis versus lift off, which assesses upper subscapularis.
  - Lift off is more accurate test for subscapularis.
  - Both pain and weakness are noted with those tests.

IMAGING

- Imaging for rotator cuff disease should begin with **plain radiographs**.
  - A Gracie view of the shoulder is a true AP view with the beam perpendicular to the scapular plane.
    - This view is used to evaluate for proximal migration of the humeral head.
    - An acromiohumeral distance of <7 mm should raise suspicion of a cuff tear.
    - Moreover sclerosis and bone spurs over the undersurface of the acromion along with great tuberosity cysts are easily visualized on this view.
    - Calcific tendinitis is seen as calcification in the subacromial space.

    - The glenohumeral joint space as well as osteophytes in the glenohumeral joint are noted.
  - Any AC joint narrowing is visualized well on Gracie view. Narrowing of the AC joint and periarticular osteophytes especially inferior osteophytes that can impinge on the cuff can be evaluated on Gracie view as well.
  - A shoulder series is incomplete without an axillary view.
    - This view is used to evaluate the glenohumeral space as well as instability and glenoid wear.
- **MRI** is routinely used to evaluate the rotator cuff.
  - Evaluation for atrophy or fatty infiltration in the cuff is very important for differentiating chronic from acute tears.
  - A good habit to get into is to start the imaging evaluation by examining the T1 sagittal cuts first to assess for atrophy/fatty infiltration.
  - It is useful to evaluate the superior cuff for tears on both coronal and sagittal cuts; T2 sequences or fat sats are useful for this step.
- Subscapularis tears are the most commonly missed cuff tears and a practitioner may be prudent to conduct physical exam and imaging evaluation of the subscapularis before examining supraspinatus.
  - A good screening tool for evaluating for subscapularis tears is to use the axial sequences and to look for fibers anteriorly 3 cuts underneath the most inferior coracoid cut, another is to evaluate for medial subluxation of the biceps tendon.
  - In patients who are not candidate to receive an MRI, a **CT arthrogram** can be very useful to evaluate both the structural integrity of the cuff and fatty atrophy, which is easily seen on CT sagittal cuts.

Conservative Treatment

- The primary goals of conservative management are to control pain, preserve and improve range of motion, and strengthen the remainder cuff, deltoid, and periscapular muscles.

- **Pain control** is accomplished by utilizing oral analgesic and anti-inflammatory medications as well as judicious use of local cortisone-based injections.
- Patients' response with local anesthetic/cortisone injection can be very useful in patients who are diagnostically challenging: patients with prior surgery and refractory symptoms, patient with multiple pain generators, patients with concomitant shoulder and neck pathology, work comp patients.
- In patients with concomitant cervical spondylosis and impingement/rotator cuff tear, subacromial injection can provide dual diagnostic and therapeutic benefits.
  - A positive response/relief of symptoms with subacromial injection predicts good prognosis with surgical intervention if the pain recurs.
  - Pain from SLAP or adhesive capsulitis does not usually improve with subacromial injection but pain from impingement or cuff tear does.
  - Similarly, local injection to the AC joint or biceps tendon can differentiate biceps tendinitis or AC sprain/arthritis from cuff/impingement pain.
- Physical and home therapy should focus on maintaining and improving **range of motion** and preventing the onset of stiffness and secondary adhesive capsulitis.
  - Preserving and/or improving range of motion, not only help preserve function, but also provide pain control.
  - A gradual gentle strengthening routine that avoids further inflammation and that focuses on strengthening the cuff, deltoid, and periscapular muscles will help preserve shoulder function and control pain as well.
- Moreover the physician or therapist should observe and correct compensatory abnormal mechanics.
  - Patients should be advised regarding proper lifting techniques, for example, lifting with the elbow supported to the side, and to avoid lifting heavy object while the shoulder is forward flexed or abducted.

- Finally, insomnia and lack of sleep due to rotator cuff tears can have devastating effect on patients' lives.
  - Patients should be questioned regarding sleeping problems and night cuff pain that wakes them up from sleep and sleeping agents can be offered.

Operative Indications

- Surgery for rotator cuff tear is indicated for select patients with symptomatic full-thickness tears, patients with acute traumatic tears, and patients with cuff tears who failed appropriate course of conservative management.
- Surgery is contraindicated in patients with
  - asymptomatic cuff tears.
  - partial-thickness tears who did not have an appropriate course of conservative management.
  - medical conditions that preclude surgery or impose high risk.
- There is weak evidence that support early surgical intervention for patients with acute traumatic rotator cuff tears.

Surgical Technique

- A diagnostic arthroscopy is carried out as described in the previous chapter.
  - The first step in fixing the cuff tear is accurate diagnosis, which means primarily **good visualization** and understanding, which tendons are involved and the morphology or architecture of the tear.
  - This supersedes the repair technique intended.
  - Hence the first step is to carry out a structured thoughtful diagnostic arthroscopy and positively visualize and identify the subscapularis, supraspinatus, bare area, and infraspinatus and posterior cuff. Good visualization is key.
  - After inspection from the articular side, the scope is inserted in the

subacromial space, subtotal bursectomy ± subacromial decompression are carried out to aid in visualization, and the cuff is carefully inspected from the bursal surface. Appropriate pump pressure, safe hypotensive anesthesia, and cautery are required to get good visualization.

  - In case of a partial-thickness tear, a suture can be passed while the scope is in the glenohumeral joint and then the bursal surface can be examined for continuity of the tear.
- A subacromial acromioplasty and subtotal bursectomy can be instrumental in achieving sufficient visualization to carry out the repair.
  - Accessory anterolateral and posterolateral portals are utilized to shuttle sutures and for instrumentation.
  - In the case of combined subscapularis and supraspinatus tear, when arthroscopic repair is planned, the subscapularis should be repaired first.
- The footprint should be debrided to get bleeding bone bed in preparation and prior to anchor placement.
  - Care should be taken in the case of using suture anchors that depend on cortical fixation (all suture anchor) to avoid aggressive decortication.
- A combined cuff release from articular and bursal surface should be done to mobilize the cuff in case of cuff retraction. Interval releases can be carried out if indicated for retracted tears. Margin convergence sutures are added as required as well.
  - Following this, suture-loaded anchors are placed and sutures are passed through the cuff.
  - Horizontal mattress sutures are preferred.
  - Arthroscopic tying technique is used to tie the sutures.
  - All anchors can be placed first, this can be done posterior to anterior, and then sutures are passed into the cuff, and then tied, tying sutures can be done anterior to posterior.
  - The sutures can be passed into knotless anchors to achieve double row fixation, although this is not proven to improve results.

- A biceps tenodesis or tenotomy should be strongly considered after subscapularis partial or full-thickness tear repair.
- Open rotator cuff repair is always an option and has similar long-term outcomes compared to arthroscopic rotator cuff repair. The operating surgeon should be familiar with both techniques.

Rehabilitation

- This depends on the size of cuff tear, method of repair, and most importantly surgeon's preferences.
  - For large/massive tears, shoulder sling with abduction pillow is utilized for 6 wks. Passive range of motion is started 4–6 wks postoperatively, active assist range of motion is started 6–8 wks postoperatively, active range of motion with weight restriction is started at 8 wks and strengthening at 10–12 wks. Shoulder ice cuff can aid with swelling and pain control. NSAIDS are discouraged after surgery. A standard physical therapy protocol and regular communication between the therapist and surgeon is very useful. Moreover, dictating the anticipated rehabilitation requirements and expectations and making those reports accessible to the therapist is helpful.
  - For patients with stiffness at the time of surgery that is refractory to preoperative rehabilitation and that requires manipulation, every attempt is made to start range-of-motion exercise and therapy immediately after surgery and without delay.

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AC JOINT

JAY BOUGHANEM

Introduction

Acromioclavicular joint pathology includes AC joint arthritis, AC joint acute and chronic instability, and distal clavicle osteolysis.

AC joint arthritis is very prevalent and is often asymptomatic. It is common even in younger patients and has an early onset in the second and third decades. It can present as pain related directly to the AC joint or as pain secondary AC joint inferior osteophytes impinging on the rotator cuff.

AC joint instability can present as acute or chronic. It can be precipitated by direct trauma to the shoulder or falls on and outstretched hand. Management of AC joint instability is contingent on acuity and classification.

Distal clavicle osteolysis is more common in males and weightlifters. Its presentation and treatment is similar to that of stable AC joint sprain or AC arthritis.

History/Presentation

- Patients with AC joint arthritis present with pain directly related to the AC joint or secondary to impingement due to AC joint osteophytes.
- For impingement pain refer to the relevant chapter.
- Pain related directly to the AC joint is usually localized over the anterior or anterolateral aspect of the shoulder and is worse with activities that require adduction of the shoulder. It is not uncommon to have pain when buckling a car's seatbelt.

- Pain can be insidious in onset or related to direct trauma to the shoulder.
- Patients may have asymptomatic pre-existing arthritis in the AC joint of the shoulder and have a fall with worsening or new pain over the AC joint.

- Patients with AC joint instability or dislocation present after shoulder trauma.
  - The most common mechanism is direct trauma to the shoulder but fall on outstretched hand can also precipitate this injury.
  - Patients have pain with adduction and in some cases acute clinical deformity over the AC joint.

Physical Exam

- The physical exam of the AC joint should include a cervical spine exam to exclude referred pain.
- A full exam of the shoulder should be conducted as well.
- Since AC joint osteophytes can precipitate shoulder impingement findings and cuff tear, Neer, Hawkins, Arc of motion, O'Brien, and shoulder strength exam should be conducted as well.
- Exam of the AC joint in particular should begin with inspection of the AC joint.
  - Any prominence or clinical deformity should be noted.
  - The examiner should look for surgical scars and atrophy of the muscle around the shoulder.
  - Tenderness over the AC joint can be specific but the examiner should examine for tenderness to palpation on both sides and ask if one side hurts more than the other.
  - Moreover, the patient should be questioned whether the tenderness is concordant with the patient's chief complaint or incidental.
  - In addition, the examiner can ask the patient to adduct the forward flexed shoulder to see if that recreates the symptoms.
- In diagnostically challenging patients and in patients with refractory

pain after prior surgical intervention with suspicion for AC joint disease, diagnostic AC joint injection may be instrumental in determining the diagnosis.

- A small amount of lidocaine ± Kenalog (or another corticosteroid) can be injected directly in the AC joint and the patient's symptoms and exam can be repeated after the injection.

IMAGING

- Plain x-rays including Grashey, AP, and axillary views can show narrowing in the AC joint, sclerosis of the joint margins, cysts, and osteophytes consistent with AC joint arthritis.
  - It should be noted that radiographic evidence of AC joint arthritis is very common in asymptomatic patients and should not constitute by itself an indication for intervention.
- Advanced imaging, especially MRI with periarticular AC joint edema can be more consistent with the patient's clinical symptoms than plain films or CT scan.
  - The AC joint can be evaluated on coronal as well as axial cuts. T2 or equivalent sequences should be carefully evaluated for fluid signal in/surrounding the joint and periarticular bone edema.
- **Classification of AC Joint Instability (According to Rockwood)**
  - AC joint instability can be classified – by Grade – based on plain views.
    - The differentiation between Grade I and II injuries is not highly clinically relevant.
      - The appearance of plain films is identical with clinical AC joint sprain with no radiographic dislocation or subluxation.
    - Grade III is $<100\%$ superior subluxation.
    - Grade IV is superior-posterior dislocation best seen on axillary or CT/MRI.
    - Grade V is $>100\%$ superior dislocation.
    - Grade VI is subcoracoid inferior dislocation.

- An MRI may be useful in situations where operative management is considered for Grade III injuries or to distinguish Grade III and V injuries.
- A CT may be useful in type IV and VI injuries to confirm plain film findings or to differentiate type III and V injuries.
- Grade V injury involves tear of deltotrapezial fascia while Grade III injuries typically do not.

Conservative Treatment

- Initial conservative management is indicated for AC joint arthritis, distal clavicle osteolysis, and AC joint instability Grade I, II, III and possibly, Grade V.
- Surgical management is preferred for instability type IV, VI and according to some authors, Grade V.
- Conservative management includes activity modification, icing, oral anti-inflammatory medications, local injection, and physical therapy.

Operative Indications

- Surgery is indicated for instability type IV, V, and VI and according to some authors, type III.
- Surgery is also indicated for AC joint arthritis, distal clavicle osteolysis, and AC joint sprains that are refractory to appropriate conservative management.

Surgical Technique

- **Distal Clavicle Resection**
  - Different techniques have been described to treat AC joint arthritis.
  - The initial technique of distal clavicle excision was described by Mumford and Gurd in 1941.
  - For the *open technique,* any skin incision can be used but Langer

lines over the AC joint are vertical and this incision is preferred.

- The deltotrapezius fascia is divided in line with the fibers of the deltoid and later repaired.
- The superior capsule is divided longitudinally tagged and preserved, the distal clavicle is excised with osteotome or sagittal saw, capsule and fascia are repaired.

- The *arthroscopic direct superior technique* described by Flatow involves anterior and superior AC arthroscopic portals.
- The *indirect arthroscopic technique* utilizes the posterior portal or preferably the lateral portal for visualization and the anterior portal for resection.
  - A 70-degree lens can provide better visualization of the posterior-superior clavicle to confirm complete resection.
  - The resection can be started with the 30-degree and finished with the 70-degree scope.
  - A posterior-superior distal clavicle remnant has been described as a cause of refractory pain due to incomplete excision of the distal clavicle.

- **AC Joint Reconstruction or Stabilization**
  - For type IV, V, and VI (type III according to some authors), surgical techniques vary based on time of injury presentation.
  - For acute injuries presenting within 2 wks of injury a Bosworth or Rockwood screw is utilized to reduce the clavicle directly to the coracoid.
  - Some surgeons prefer using suture constructs (tight rope or ENDOBUTTON type device) but some complications have been described with that.
  - Other surgeons prefer a hook plate, which is associated with a larger scar but easier technique.
  - Rockwood/Bosworth screw and hook plates have to be removed in 8–12 wks.
- For chronic or subacute injuries reconstruction of the AC joint is required.

- Different techniques are described including coracoacromial ligament transfer, auto of allograft reconstruction, suture repair for augmentation.
  - Autograft or allograft can be wrapped around or fixed to the coracoid and then fixed to the clavicle to provide anatomic or nonanatomic reconstruction of the coracoclavicular ligaments and AC superior capsule.
  - Soft tissue fixation can be augmented with suture fixation.
- Outcomes of acute repairs are better than outcome of chronic reconstruction and many surgeons prefer to treat chronic AC joint dislocation nonoperatively due to diminished outcomes of operative repair.

Rehabilitation and Postoperative Care

- Shoulder is immobilized in a shoulder sling for 6–8 wks. Passive range of motion can be started at the surgeon's discretion 4–6 wks postoperatively. Active assist range of motion 4–8 wks after surgery, and active range of motion 8 wks after surgery. Shoulder strengthening and discontinuing weight restrictions can be initiated 8–10 wks postoperatively.

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THE BICEPS BRACHII—LONG HEAD PATHOLOGY, SLAP, AND DISTAL RUPTURE

JAY BOUGHANEM

Anatomy and Physiology

The biceps originates from 2 heads. The short head is, along with brachialis, part of the conjoined tendon originating at the tip of the coracoid process. The long head's origin is at the biceps anchor of the superior glenoid labrum. Both heads join up to form the biceps belly, which runs lateral to the median nerve and brachial artery. The musculotendinous junction of the long head is at the level of the inferior pectoralis major or just distal to that. The distal insertion of the biceps is lateral to the tendon of brachialis, which inserts at the coronoid process of the proximal ulna and runs just lateral to the brachial artery. The biceps tendon inserts on the proximal radius over the radial tuberosity, which is a palpable prominence distal to the radial neck, has a 90-degree ulnar position in relationship to the radial styloid distally.

Distal biceps rupture is associated with 50% loss of supination strength and 20–30% loss of elbow flexion strength.

Longhead of biceps rupture or biceps tenotomy is associated with 20% elbow flexion loss and 10% supination loss.

Loss of strength is partially mitigated by long head tenodesis.

The Long Head-Proximal Biceps

History/Presentation

- Patients with biceps tendinitis present with pain over the proximal anterior aspect of the humerus.
  - Pain is exacerbated with activities that require elbow flexion and supination especially with shoulder abduction.
- Patients with proximal biceps long head rupture present with acute deformity with a distally migrated biceps belly often after mechanism that involves forceful extension or pronation of a flexed/supinated elbow.
  - The deformity may be preceded with biceps tendinitis and pain.
- A full shoulder exam including cuff exam with special focus on subscapularis is carried out.
  - Subscapularis ruptures can be associated with biceps tendonitis and medial subluxation or dislocation.

Physical Exam

- Patients have pain to palpation over the mid anterior aspect of the humerus with the arm in 10 degrees of internal rotation.
- In some patients, soft tissue prominence or swelling can be appreciated over the anterior proximal shoulder.
- Patients have pain with Speed test—pain over the bicipital groove with resisted forward flexion of the shoulder.
  - Yergason test or resisted supination of the flexed elbow is also positive.

Imaging

- MRI is useful in evaluation for tendinitis with fluid in the bicipital groove on T2 sequences.
- With biceps rupture, an empty bicipital groove is evident on axial T1 and T2 cuts.
- Medial subluxation or dislocation is often associated with subscapularis tear also best seen on axial cuts.
- SLAP lesions are evaluated on coronal sequence and intra-articular contrast may facilitate radiographic diagnosis.

Nonoperative Management

- Nonoperative management is the 1st line of treatment for biceps tendinitis.
  - It comprises activity modification, oral anti-inflammatory medications, physical therapy and local injections.
- Local injections are associated with theoretical risk of rupture, which should be discussed with the patient.
- For long head of the biceps rupture, operative and nonoperative management are indicated based on patient characteristics and preferences.

Operative Management

- This type of management may be indicated in patients who are intolerant of the cosmetic deformity or loss of strength associated with the rupture.
- The expected benefit of surgery and possible risks are explained to the patient to aid in decision making.

Surgical Indications

- Biceps tenotomy or tenodesis is indicated in patients with biceps tendinitis with >50% tendon rupture.
- Biceps debridement is an option in patients with <50% rupture.
- Biceps tenodesis is indicated in patients with biceps rupture who are intolerant to the cosmetic deformity of the weakness or who prefer surgical intervention after discussion of risks and benefits.

Surgical Technique

- Many techniques can be utilized.
  - For debridement, standard posterior and anterior portals are established.
  - A probe is used to pull the biceps into the glenohumeral joint for full visualization.
  - A motorized shaver can be used to débride the tendon. Basket or cautery can be used to perform a tenotomy.

- For biceps tenodesis, open subpectoral tenodesis may have superior outcome with less anterior bicipital groove pain.
- For open subpectoral tenodesis a beach chair position is used.
  - The arm is positioned in abduction and external rotation.
  - An incision is made over the anterior shoulder axilla; it can be longitudinal or transverse.
    - Blunt finger dissection is carried down subpectorally to the bicipital groove.
    - The biceps is palpated and a blunt Homan retractor is placed lateral and another is placed medial to the biceps.
    - Determine tenodesis site at physiologic length.
    - Mark the site of tenodesis over biceps and bone.
    - Carry out an arthroscopic biceps tenotomy as described above.
    - Many fixation methods can be used.
      - An anchor is one option.
      - The anchor is placed in the bicipital groove subpectorally and 1 limb is passed as a locking Krakow type stitch and the other limb as a simple pass.
      - Excess tendon is excised.
      - Pulling on the simple pass suture reduced the biceps to the groove and the 2 limbs are then tied.
      - This can be repeated with a double-loaded anchor.

Biceps Anchor-Superior Labrum Anterior to Posterior Lesion of SLAP Lesions

Presentation

- Patients with SLAP lesions often present with shoulder pain with associated mechanical symptoms of locking, catching, and giving out.
  - Pain is often recreated with activities that require forceful flexion

  with an extended elbow.
  - The pain can be anterior or posterior.
  - The mechanical symptoms are key in differentiating biceps anchor pain from other shoulder pathology.
- Patients with SLAP lesions respond favorably to glenohumeral local injections.
- SLAP lesions are often associated with other shoulder pathologies including impingement, AC joint arthritis, and cuff tear.

Physical Exam

- Active compression or O'Brien is positive on physical exam.
- In this test, the patient brings the shoulder into position of 90 degrees of forward flexion with neutral adduction.
- The patient resists forward flexion with the arm in maximum internal and external rotation. Worse pain in internal rotation indicates a positive test.

Nonoperative Management

- Nonoperative management is the 1st line of treatment.
  - It comprises activity modification, oral anti-inflammatory medications, physical therapy and local injections.
  - Intra-articular glenohumeral joint injection with combination of local anesthetic/steroid can be used for diagnostic and therapeutic purposes.
- Fluoroscopic guidance increases accuracy of intra-articular joint injections.

Surgical Indications

- Surgery is indicated in patients who are refectory to an appropriate course of conservative management.
  - Surgical options include SLAP debridement, SLAP repair, and Biceps Tenodesis.
- Debridement is indicated in stable lesions that do not involve complete avulsion of the superior labrum/biceps anchor off the

superior glenoid.

- Repair and tenodesis are indicated for unstable lesions.
  - Repair is indicated in young patients who are overhead athletes and is associated with higher failure rates.
  - Tenodesis is indicated in patients who are older, who are not involved with overhead sports, and those who have refractory symptoms or retear after SLAP repair.

Surgical Technique

- Standard anterior and posterior portals are used for arthroscopic evaluation.
- A probe is used to assess for stability of the slap lesion and the shoulder is also taken through range of motion with the camera in the GH space to assess for tear stability as well.
  - The biceps is pulled into the joint for assessment of concomitant biceps pathology or extension of the tendon into the biceps substance.
  - The cuff is carefully examined.
  - Cuff pathology, like subscapularis tear may influence intraoperative decision making.
  - Biceps tenodesis or tenotomy is preferred when a subscapularis tear is evident.
  - Tenotomy or tenodesis is carried out as described in the preceding section.

Biceps Insertion-Distal Biceps

History/Presentation

- The biceps insert at the bicipital tuberosity of the proximal humerus.
- Distal biceps rupture is most common in middle-aged males.
- Complete rupture is more painful than partial rupture.
- Patients present after traumatic injury, which may involve forced extension/pronation of the flexed/supinated elbow with eccentric

contracture of the biceps muscle.

- In acute presentation, the patient has ecchymosis over the flexor compartment of the distal arm with tenderness over bicipital tuberosity.
- In subacute presentation the ecchymosis is resolved but the patient may have deformity over the flexion crease of the elbow.
- The patient may complain of pain, deformity, and weakness with elbow flexion/supination.

Physical Exam

- The hook test attempts to hook the biceps tendon with elbow flexed and the patient supinating against resistance with the examiner hooking the biceps over the involved and uninvolved sides.
- Comparison of elbow flexion and supination strength in both sides is often helpful with notably diminished strength especially in supination in the involved side.
- In subacute or chronic presentation, there is a puckered skin deformity associated with proximal retraction of the biceps that may be exacerbated with active biceps contracture.

Imaging

- Plain films should be evaluated to exclude any concomitant trauma or injury.
- MRI is very useful in confirming the diagnosis as well as to determine the level of proximal migration of the biceps stump.
- Axial cuts will show a bare bicipital tuberosity.
- Sagittal cuts will show the level of migration and the fluid in the bicipital fascial compartment.

Nonoperative Management

- Nonoperative management is an option.
- Full discussion of expected limitation in elbow flexion and supination should be carried out.
- Patient is managed symptomatically with icing/elevation/anti-inflammatory medication.

- Range of motion and strengthening can be initiated when adequate pain control is achieved.

Surgical Technique

- Multiple techniques can be used.
- The single incision technique with cortical button fixation provides fast and reproducible fixation with the strongest fixation method.
- **Positioning**
  - The patient is positioned supine with the affected upper extremity on a radiolucent arm board.
  - The extremity is prepped and draped and a sterile tourniquet is applied over the proximal humerus.
- **Exposure**
  - A transverse or longitudinal incision can be used.
  - Extensile incision is preferred for subacute or chronic ruptures.
    - The brachial artery medial to the brachialis is palpated and marked.
    - The lateral antebrachial cutaneous nerve, if encountered, is tagged and protected.
    - The ulnar border of the brachioradialis is followed to identify and protect the sensory branch of the radial nerve.
    - The biceps fascia is open and following the fascia proximally will lead to the stump.
    - A Krakow or whipstitch is applied to the distal stump.
    - Following the fascial compartment distally will lead to the tuberosity.
  - The radial tuberosity is at 90 degrees relationship to the radial styloid.
    - With the forearm in full supination, the radial tuberosity should be straight anterior distal to the humeral neck and should be easily palpable as a prominence.
    - 2 Homan retractors are based on both sides of the tuberosity.

- **Radius preparation**
  - A bicortical guidewire is placed in the proximal center of the tuberosity in a radial to ulnar direction, 30-degree angle toward the ulna.
  - The distal stump with the stitch-in is sized (usually size 7 or 8 mm).
  - The proximal and distal cortices are drilled over the guidewire to accommodate the cortical button passage.
  - The proximal cortex only is drilled/reamed based on the size of the stump to accommodate the stump.
  - The cortical fixation button is applied to the strands of the whip or Krakow stitch and the cortical button is passed past the distal cortex and deployed.
  - The elbow is placed in supination and flexion and the biceps is pulled into the proximal humerus and an interference screw may be used for adjuvant fixation.
  - The suture ends are tied over.
  - The incision is closed and a splint with the elbow in flexion and neutral rotation or supination is applied.

Postoperative Rehabilitation

- Elbow is initially maintained in flexion and gradual elbow extension is regained over 6–8 wks.

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SHOULDER INSTABILITY

HANY EL-RASHIDY

Shoulder Anatomy and Pathoanatomy

The *glenohumeral* (GH) *joint* allows motion in multiple planes. Stability is conferred by both static stabilizers (glenoid concavity, labrum, capsule, and ligamentous restraints) and dynamic (scapular and rotator cuff) stabilizers.

Three groups of *GH ligaments* (superior, middle, and inferior) resist GH translation at varying degrees of abduction (anterior band of IGHL most important in the at-risk position of 90° of abduction and external rotation). Middle GH ligament runs across subscap (patients can have normal variants including Buford complex).

Both *scapular and rotator cuff musculature* keep glenoid aligned and compress humeral head into glenoid. In the healthy shoulder, strengthening and neuromuscular training help optimize neuromuscular control of the GH joint.

Glenohumeral Instability

- Encompasses a wide spectrum of injury from microinstability to dislocation.
- 85% of these events involve anterior instability but can also be posterior (seizures, electric shock, trauma) or inferior.
- It is important to distinguish laxity (increased translation but asymptomatic) vs. instability where symptoms occur in conjunction with increased laxity.
- There are traditionally 2 types:
  - **Traumatic/unidirectional instability: TUBS—**Traumatic, **U**nidirectional, **B**ankart lesion is common, **S**urgery is often

required.

- In young athletes, traumatic anterior dislocation has been shown to result in a high incidence of avulsion of the anteroinferior glenoid labrum (i.e., Bankart lesion) as well as Hill–Sachs lesions.
- With this injury, the bumper effect of the labrum is eliminated as is the sling effect of IGHL with abduction.
- The Bankart lesion is the “essential lesion” of instability.
  - Studies show it is present between 79% and 100% after initial dislocation and 93–97% of recurrent instability.
  - Studies suggest that recurrence depends on patient age and activity level with a much higher incidence in active patients < 23 yrs.
  - Even higher recurrence rates found in young athletes participating in contact sports (> 90%).
- Recurrent instability is also associated with acute (Bony Bankart) or chronic (glenoid deficiency) bony involvement.
  - Arthroscopically, look for a change of the normal pear-shaped glenoid to an inverted pear appearance.

- **Atraumatic or Multidirectional Instability (MDI): AMBRI —A**traumatic, **M**ultidirectional, often **B**ilateral, usually responds to **R**ehab if surgery is needed it involves **I**nferior capsular shift
  - Associated with generalized joint laxity (flexible, adolescent male and females).
  - Often bilateral, often positive family history, instability with minimal trauma or mechanism.

History/Presentation

- Patient may or may not recall a specific traumatic event.
  - Often it can be numerous partial subluxation events or they may describe generalized laxity of both shoulders.
  - It is important to determine mechanism of injury (traumatic vs.

atraumatic) and if this was the initial occurrence vs. a repeated event.

  - Ask about mechanical symptoms.
  - Patients may describe anxiety/apprehension with arm abducted and externally rotated.
- Ask about frequency of symptoms.
  - MDI may present with insidious onset and nonspecific symptoms (activity-related pain in 2nd or 3rd decade of life).
  - Identify specific inciting events or positions (patients may avoid certain provocative positions or activities).

Differential Diagnosis

- Proximal humerus fractures and scapular fractures—deformity, swelling, evaluation of x-rays carefully.
- Acromioclavicular or sternoclavicular dislocation—look for asymmetry compared with contralateral joints and evaluate imaging.
- Cervical radiculitis—look for neurologic symptoms (numbness, tingling, paresthesias).
- Thorough neurovascular exam, Spurling maneuver.
- Scapulothoracic crepitus—evaluate for scapular dyskinesia and palpable posterior snapping/crepitus.

Physical Exam

- **Acute dislocation:** palpable prominence of humeral head anterior and inferior to shoulder, abnormal shoulder contour, arm held adducted and internally rotated, limited motion.
  - Always examine cervical spine.
  - **Inspection:** Asymmetry, atrophy, previous incisions.
  - **Palpation:** AC joint, bicipital groove.

- **Motion:** Both active range of motion (AROM) and passive range of motion (PROM).
- **Strength:** scapular muscles, deltoid, biceps, triceps, and rotator cuff.
  - Perform full neurovascular exam.
  - Test for generalized ligamentous laxity (hypermobile patella, hyperextensible elbow, and thumb MPs).
- Specific **stability tests** include the following:
  - **Sulcus sign** (measures inferior laxity)
    - With arm neutral/adducted, longitudinal inferior traction is applied; measure distance from acromion to humeral head (1 cm = 1+, 2 cm = 2+, 3 cm = 3+).
    - Test again in 30° ER.
    - If still positive, this suggests incompetence of superior GH ligament.
    - Elimination in ER suggests competent rotator interval.
    - Positive sulcus with arm at 90° of abduction = inferior capsular laxity.
  - **Apprehension:** Patient supine, arm abducted to 90° and gentle ER, guarding or apprehension = positive apprehension.
  - **Relocation:** From this position, posteriorly directed force improves symptoms.
    - Surprise: sudden release of posterior force causes recurrence of apprehension (most accurate of the 3 tests).
- **Load and shift:** patient supine with shoulder at edge of table.
  - With arm abducted in plane of scapula, place a small axial load to center glenoid.
  - Then translate proximal humerus anterior-inferior and posterior.
  - Grade 1—translation to glenoid rim
  - Grade 2—past rim but spontaneous reduction
  - Grade 3—dislocation without spontaneous reduction

Imaging

- **Plain films:** Shoulder series includes AP, true AP (Grashey), scapular Y and axillary lateral (CRITICAL to get pre- AND postreduction axillary views on every dislocation).
  - Evaluate for Hill–Sachs or bony Bankart injury.
- MRI (arthrogram preferred)
  - Look for Bankart lesion (tear, avulsion of AI capsulolabral ligamentous complex) and Hill–Sachs (defect in posterolateral humeral head), evaluate for rotator cuff tear and other associated injuries.
  - In MDI, arthrogram will show **patulous capsule** or **increased GH volume**
- **CT:** Assess for bony Bankart injury (fracture of AI glenoid) and chronic glenoid deficiency (can quantify with 3D reconstruction).

Prevention

- Adequate off-season training, appropriate technique (i.e., tackling), proper equipment selection, keep dynamic stabilizers conditioned.

Nonoperative Management

- Initial management of traumatic instability includes emergent reduction, often under sedation or anesthesia
- Traction on abducted and flexed arm with countertraction on the body (sheet in axilla).
- Other reduction techniques
  - **Stimson:** patient prone with downward traction (weight on wrist).
  - **Spaso:** with patient supine, gentle longitudinal traction as you forward flex and ER.
  - Postreduction management includes: POST-OP X-RAY INCLUDING AXILLARY VIEWS AND NV EXAM!

- Then, temporary immobilization (3–10 d) in a sling and early rehab to achieve full pain-free ROM.
- Patient focuses on early ROM with progression to strengthening (focus on dynamic stabilizers) by 3 wks.
- Return to sports varies by individual and activity.
- Can return with motion limiting brace.

- For most MDI patients, rehabilitation is treatment of choice.
  - Treat scapular dyskinesia to improve glenoid position and dynamic stabilization.
  - Focus on preferential strengthening of the rotator cuff.
  - Most reports show excellent results with non-op treatment of MFI.
  - This should be a minimum of 6 mos before considering surgical interventions.

Operative Indications

- Absolute—Recurrent instability (or pain) despite maximum nonoperative measures (immobilization, activity modification, rehab).
  - This can be for recurrent traumatic OR atraumatic instability.
- Associated rotator cuff tear or glenoid defect $>25\%$, proximal humeral fracture (i.e., displaced GT fracture).
- Irreducible dislocation or nonconcentric reduction (interposed tissue).
- Relative—Overhead throwing athlete or contact sport athlete, age <20.

Contraindications

- Acute infection, noncompliant individuals, limited ROM.
- Patients with significant bone loss (i.e., $>25\%$ anterior glenoid) may require Latarjet procedure (coracoid transfer).

Surgical Technique

1. Arthroscopic Anterior Stabilization (Bankart Repair)

A. Pre-op area

- Verify history and consent in pre-op.
- Be aware of anesthesia plan, antibiotics.
- Mark operative site.
- Interscalene blocks or catheters are extremely useful for analgesia intra- and post-op.

B. Positioning

- Lateral decubitus or beach-chair.
  - For lateral decubitus, remember to place axillary roll (just distal to axilla).
  - Stabilize body with beanbag, flex knees and place padding under down leg and in between legs.
  - Tilt table posteriorly 20° to orient glenoid horizontally.
  - Place arm in balanced traction (with 10–15 lb of traction) in 30–45° of abduction and 20° of forward flexion.
  - Use a 3-point distraction system for better GH distraction and visualization.

C. Procedure

- Before positioning, perform exam under anesthesia (EUA) on BOTH extremities to confirm direction of instability and motion.
  - Then prep, drape, and perform surgical time-out.
- After marking out bony anatomy, establish posterior viewing portal in "soft spot" (1 cm inferior and 2 cm medial to posterolateral corner of acromion).
- Use outside-in technique with spinal needle localization to establish 2 further portals anteriorly.
- Anteroinferior portal (just above subscap, ensure appropriate angle to glenoid) and anterosuperolateral (AS) just anterior to

leading edge of supraspinatus around biceps.

  - After verifying trajectory with spinal, make small incision with 11 blade, followed by Wissinger rod, followed by cannulas (may need dilator system for larger cannulas).

- Space 2 anterior cannulas as much as possible to avoid OVERCROWDING.
- Perform thorough diagnostic arthroscopy, evaluate rotator cuff, ligaments, capsule, articular cartilage, biceps, all labral lesions, and the size of any bone defect (glenoid and Hill–Sachs).
- Viewing from posterior and/or AS portal, prepare the capsule and labrum.
  - Begin with arthroscopic elevators (especially necessary if labrum is healed medially as in ALPSA lesion) and work from lateral to medial.
  - Prep capsule with rasp or shaver on forward.
  - Prep glenoid to bleeding, cancellous bone with burr or high-speed shaver.
- Begin placing anchors, starting with most inferior (thru AI portal or percutaneous) and place 3–4 total, advancing superior by ~5 mm with each anchor.
  - Place anchor at 45 degrees to glenoid and on edge or 1–2 mm onto face (not medial).
- Separate sutures by retrieving 1 out of 1 cannula.
  - Then use 1 of several commercially available suture-passing devices with a sharp twist to pierce capsule and torn labrum and exit on face of glenoid.
  - With the first, most inferior anchor, it is critical that this capsular bite is inferior to anchor to achieve an “Inferior to Superior” shift.
  - Retrieve out of same cannula suture was retrieved from and relay suture back thru passed tissue and out AI cannula.
  - Tie down with surgeon’s choice of arthroscopic knot.
  - Repeat 2–3 times for remaining anchors to complete repair.

D. Final steps

- The joint is thoroughly irrigated and the portal sites are routinely closed.
- A soft dressing is applied followed by a cooling unit and ultra-sling (with abduction pillow).

2. Open Anterior Stabilization

A. Positioning

- Beach chair—captain's chair or beanbag.
  - Head elevated 30–45 degrees, knees flexed, head secured.
  - Bump (2-folded towels) under scapula to stabilize and deliver glenoid.
  - Drape arm free (can rest on padded mayo or use commercially available pneumatic arm holder).

B. Procedure

- Standard deltopectoral approach is used with incision from coracoid (or just lateral) toward axillary fold.
  - Develop full-thickness flaps and ID fat stripe and DP interval. ID cephalic vein and take lateral with deltoid, develop interval bluntly.
  - Identify coracoid and conjoined tendon, incise clavipectoral fascia, and place deep self-retaining retractors.
- Define subscap, ligate anterior humeral circumflex vessels and take down upper ⅔ of subscap, leaving cuff of tissue to repair to.
  - Place retractor on medial neck of glenoid to facilitate exposure.
- Mark and incise medial capsule from superior to inferior and mobilize.
  - Prep AI glenoid to bleeding bone and place 3–4 anchors from inferior to superior.
- Sutures are then passed to effect a superior capsular shift and tied from inferior to superior with arm in 30 degrees of forward flexion and external rotation.

- Then reexamine for stability.

C. Final steps

- Secure subscap repair is critical.
  - Anatomic reapproximation and repair with #2 nonabsorbable suture followed by running closure of DP interval with 2-0 vicryl, subcutaneous buried 2-0 vicryls, and either staples or running subcuticular stitch.

3. Arthroscopic Treatment of Multidirectional Instability (Arthroscopic Capsular Plication)

A. Positioning and Prep

- Lateral decubitus or beach chair (as for anterior instability). Perform pre-op exam and EUA.

B. Procedure

- Establish posterior portal, 2 anterior portals, and perform diagnostic arthroscopy as for anterior instability.
  - Notice ease with which arthroscope can be advanced between glenoid and humeral head (commonly called "drive-thru sign").
  - Now switch to viewing from AS portal.
- Abrade anterior capsule with rasp or shaver and begin placing plication stitches.
  - The first is placed at 5:30 (right shoulder) and if intact, the labrum is used as an anchor.
  - Use suture shuttle device to pierce capsule, first inside-out, and then outside-in to grab 1–2 mm of capsule.
  - Then pass underneath labrum, deploy wire relay, grasp from free posterior portal, relay high tensile strength suture thru posterior portal, labrum, capsule, and out AI portal.
  - Retrieve other limb from posterior limb and tie arthroscopic knot.
  - Place 2 additional plication sutures moving superior. Use limb exiting from capsule as post.
- While still viewing from AS portal, abrade posterior capsule and

repeat these steps to place plication stitches posteriorly for a balance plication.

- Again, if labrum is torn or not robust, suture anchors can be used in glenoid.

C. Final steps

- The joint is thoroughly irrigated and the portal sites are routinely closed.
- A soft dressing is applied followed by a cooling unit and ultra-sling (with abduction pillow).

Postoperative Rehab and Expectations

- Patients are maintained in a sling for 4–6 wks.
- Begin pendulums in the first 1–2 d and PT begins by 7–10 d.
- Motion is limited to PROM (passive supine forward elevation).
- Begin AROM by week 5–6 and strengthening between week 8 and 12 (varies with each surgeon).
- Begin interval, sports-specific drills at 4 mos and overhead lifting at 6 mos.
- **Most important**
  - Explain to the patient that the rehabilitation process is long and difficult.
  - Stress the importance of compliance with restrictions to achieve successful results.

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SHOULDER ARTHRITIS

JAY BOUGHANEM

Introduction

Degenerative joint disease of the glenohumeral joint can result from different conditions including rheumatoid arthritis, posttraumatic arthritis, osteonecrosis, crystalline disease, iatrogenic after instability surgery, rotator cuff arthropathy, and osteoarthritis—which is a diagnosis of exclusion.

It is not clear whether the iatrogenic arthritis that is often seen after instability surgery is due to the natural history of shoulder instability considering the cartilage injury sustained with multiple dislocations sustained prior to surgery or whether it is a side outcome of changing the force couples and joint stress forces with surgery, or a combination of both factors.

Rotator cuff arthropathy is subclassified as a distinct category due to different presentation, etiology, and management.

History/Presentation

- Patients with degenerative joint disease of the glenohumeral joint usually present with pain, weakness, limited range of motion, and morning stiffness.
  - Pain is deep achy in nature, worse with activities that require motion and lifting; rest pain is not uncommon.
  - In contrast to rotator cuff pain, the pain with shoulder arthritis is present even when the shoulder is at low angles of shoulder elevation/abduction and the elbow is at the side.
  - There is often crepitus with range of motion.

- The patient should be questioned regarding the time of onset of pain or disability, any prior trauma or injuries, prior surgery, personal or family history of rheumatoid or crystalline disease, prior evaluation and/or management.
  - Also question limitation of ability to perform activities of daily living and/or recreational activities that are imposed by the shoulder problem.

Physical Exam

- The physical exam of shoulder starts with examination of the cervical spine.
- Exam of the shoulder includes active range of motion in forward flexion, abduction, external rotation, and internal rotation.
  - Active range of motion should be measured in both shoulders for comparison.
  - Furthermore the passive range of motion should be checked if there is any limitation to active range of motion.
  - Crepitus in the glenohumeral joint is easily palpable with the examiners hand over the shoulder while taking the shoulder through a gentle passive range of motion.
- After checking range of motion, both shoulders should be inspected carefully checking for any deltoid, supraspinatus, infraspinatus atrophy, surgical scars, anterior superior escape, subdeltoid and glenohumeral crepitus.
- Patient with glenohumeral arthritis have pain with palpation over the posterior glenohumeral joint line and anterior glenohumeral joint line.
- In diagnostically challenging patient, for example, early glenohumeral arthritis presentation, concomitant diagnosis, a diagnostic glenohumeral joint injection may be instrumental in determining the main pain generator.
  - A small amount of Lidocaine with or without Kenalog (or another corticosteroid) can be injected directly in the GH joint and the patient's symptoms and exam can be reevaluated after the

injection.

- Shoulder exam should include strength testing and full rotator cuff exam with careful evaluation of external rotation strength with the elbow at the side (infraspinatus) pain with resisted external rotation of elbow at the side (infraspinatus) and external rotation lag sign (infraspinatus).
  - Posterior cuff is also tested with the arm held in 90 degree of abduction (infraspinatus) for strength in external rotation as well as any external rotation lag or inability to hold the arm externally rotated against gravity (Hornblower sign).
- Belly press and lift off are used to assess subscapularis.
- Supraspinatus is tested with the arm in 90° of abduction and internal rotation in the scapular plane—pain and weakness with resisted abduction are noted.
- Sometimes it is not possible to know whether weakness is due to structural abnormality or pain, in those scenarios, a glenohumeral injection may aid in alleviating the pain and getting more accurate strength assessment.

Imaging

- Plain x-rays including Grashey, AP, and axillary views can show narrowing in the GH joint, sclerosis of the joint margins, cysts, and osteophytes consistent with GH joint arthritis. Axillary views should be used to evaluate for glenoid retroversion and bone stock available for reconstruction; a biconcave glenoid, which is a contraindication to hemiarthroplasty.
- The acromiohumeral distance should be measured. A distance under 7 mm indicates proximal migration of the humeral head and cuff tear.
- Advanced imaging, especially MRI can be done to evaluate the rotator cuff and deltoid muscles as well as glenoid wear.
  - The rotator cuff should be evaluated for atrophy (seen best on parasagittal T1 sequences or CT) as well as cuff tears.
  - Coronal and sagittal projections are used for supraspinatus and

axillary cuts are used for subscapularis and posterior cuff.

Conservative Treatment

- Initial conservative management is indicated for GH joint arthritis and includes activity modification, icing, oral anti-inflammatory medications, local injection, and physical therapy.
  - Viscosupplementation has shown a statistically significant but minimal clinical benefit according to some studies.
  - Glenohumeral injection is more successful if done under fluoroscopy but a blind injection can be attempted at first especially if the surgeon performs frequent shoulder arthroscopies since the needle path mirrors the implementation of a standard posterior portal.
- Patients with more preserved range of motion usually have less discomfort compared to patients with significant stiffness and an intra-articular glenohumeral joint injection may aide the patient and the therapist regain range of motion.
  - This is helpful even in patients who are contemplating surgical interventions as it facilitates the postoperative rehabilitation after shoulder replacement.

Operative Indications

- Surgery is indicated for patients with pain and disability that is refractory to a course of appropriate conservative management.
- Standard total shoulder arthroplasty has superior outcome compared to shoulder hemiarthroplasty and is indicated in patients with glenohumeral arthritis with intact rotator cuff or with a small cuff tear.
  - The outcomes in patients without a cuff tear or with a small cuff tear are equivalent.
  - Atrophy and fatty infiltration of the cuff seen best on MRI sagittal cuts is a more relevant finding when it comes to deciding whether a standard or reverse shoulder arthroplasty is required.

- A biconcave glenoid is a contraindication to hemiarthroplasty.

Surgical Technique

Hemiarthroplasty and Total Shoulder Replacement

- Preoperative planning
  - Preoperatively, the plain images and 3D images are evaluated carefully to assess the integrity of the cuff and availability of adequate bone stock.
  - The version of the glenoid is measured using axial images caudal to the base of the coracoid.
  - Excessive retroversion or bone stock loss may change the operative plan; version can be corrected by preferential anterior reaming.
  - Preoperative planning should also include templating of the humerus to estimate the size of the humeral stem and glenoid.
    - Axillary views can be used to template the glenoid and Gracie views for the humeral stem.
    - The patient should be evaluated for any cervical pathology as that may affect appropriate intraoperative positioning.
- Positioning
  - The main goal of appropriate positioning in shoulder replacement surgery is to facilitate the glenoid exposure, which is usually the most challenging part of the procedure; moreover, glenoid component failure is the main cause of total shoulder replacement failure.
    - Supine or beach chair positions can be used. Head of the table should be raised 30 degrees or less if beach chair position is used.
    - A wrapped towel is applied behind the medial border of the scapula.
    - If a tenant positioner is used, the movable hard surface is placed behind the scapula to stabilize it, this is done, so that the humeral head can be retracted later behind and inferior to the

glenoid for better exposure. If the scapula is not supported, glenoid exposure is more difficult.

    - This should be done carefully without impeding adduction to the humerus for proximal humeral exposure.
    - The cervical spine can be gently rotated/laterally bent slightly away from the shoulder to allow for better proximal humerus exposure during reaming and broaching.
    - Both shoulders are examined under anesthesia, discrepancy in passive range of motion is noted.

- Initial exposure
  - A deltopectoral approach is used.
  - The incision starts over the coracoid and is carried to the deltoid tuberosity of humerus.
  - The first landmarks are base of coracoid and fat strap between deltoid and pec. major.
    - The fat strap is followed from the base of coracoid and distally.
    - The cephalic vein is identified and retracted either medial or lateral.
    - Medial retraction of the cephalic may avoid iatrogenic injury from the deltoid Brown retractor.
    - The deltopectoral fascia is incised.
    - The anterior circumflex artery and veins can be identified and ligated.
  - The second landmarks are long head of biceps and base of coracoid, which leads to the rotator interval
    - The biceps tendon is identified, followed proximally to the rotator interval, cut proximally and tenodesed to pectoralis major fascia. Check MRI to see if present on axial images or spontaneous rupture has occurred.
  - The shoulder is then placed in abduction and release of any subdeltoid adhesions is undertaken with careful attention to mobilize anterior, lateral, and posterior deltoid.
  - The medial aspect of the bicipital groove is the third landmark.

    - The lateral borders of subscapularis are easily visualized after identification of bicipital groove and its medial border.
    - A blunt Homan can be placed in the rotator interval to help isolate the subscapularis.
    - A subscapularis peel off, tenotomy, or lesser tuberosity osteotomy can be used to gain access to the joint.
- Humerus preparation
  - The humerus is delivered into the wound with adduction and external rotation.
    - Cuff is visualized and retracted.
    - Version and neck to shaft angle are determined and the proximal humerus cut is made.
    - The proximal humerus cut should attempt to reflect appropriate neck shaft angle (average 135 degrees range 120–150 degrees), a shallow cut is better than a more vertical cut.
    - The cut should also recreate appropriate version which is 0–20 degrees of retroversion, were retroversion is the angle of the forearm which is perpendicular to the epicondylar axis and the articular plane of the humeral head.
    - The humeral head is in 0–20 degrees of retroversion.
    - See Figure 3.1 for explanation of humerus retroversion.
  - The humeral canal is entered just posterior to the bicipital groove and the humerus is **hand** reamed and broached based on preoperative x-ray templating until a good rotational fit is reached.
    - The humeral head is sized with attention to avoid overstuffing of the joint.
    - The superior portion of the humeral surface is 5 mm from the greater tuberosity and 5 cm from the proximal border of the pectoralis major.
  - If hemiarthroplasty is contemplated, the shoulder is examined with the trail components in place.
    - No more than half a glenoid translation anterior or posterior

should be present with paralysis reversed.

- Subscapularis should be checked for contracture and a blunt release by opening a curved mayo between the subscapularis fossa and muscle belly is carried out if indicated.

- Glenoid exposure
  - First, the interval between conjoined tendon and subscapularis can be explored and the axillary artery is identified with a vessel loop.
    - A capsular release is necessary for good glenoid exposure.

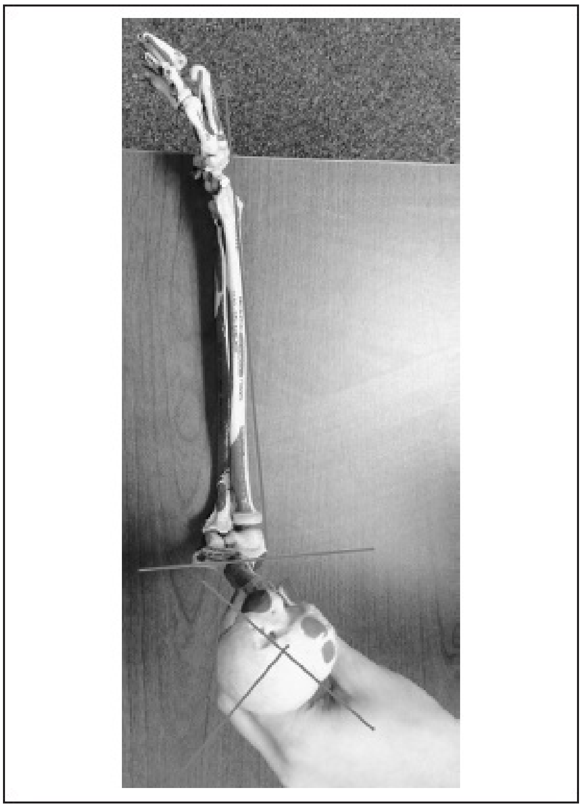

Figure 3.1 Humeral retroversion refers to the posteriorly facing articular surface in relationship to the epicondylar axis of the distal humerus. In this anatomic specimen, the version is determined by first, the epicondylar axis or the line connecting the lateral and medial epicondyles; and second, a line perpendicular to the articular plane of the humeral head.

- A fukuda retractor is applied with the shoulder in adduction and neural rotation and then it is externally rotated gradually with attention to the inferior capsule.
- With a retractor placed between capsule and axillary nerve, the

inferior capsule is gradually released until the humeral head can be mobilized and retracted using a fukuda or blunt Homan behind and inferior to the inferior posterior aspect of the glenoid.

- Difficulty in this step may indicate inadequate release of deltoid or require some release of capsule and/or triceps.

- Glenoid preparation
  - The center of the articular surface of the glenoid is determined by the intersection of the midaxial line and midcoronal line.
  - A guidewire is applied based on preoperative measurement of glenoid surface version to attempt to correct or partially correct for glenoid retroversion.
  - A positive sign of the correction is initial anterior preferential reaming of the surface of the glenoid (this is in comparison to a reverse shoulder where preferential inferior reaming and a "smiley face" is sought).
  - The subchondral surface hard bone should be **reached but not breached**.
  - Pegged all poly glenoid has improved survival compared to keeled glenoid and should be attempted if bone stock is sufficient.
  - The bone should be dried (epinephrine-soaked sponge can be used) and the cement should be pressurized into the peg holes or keel slot, the poly applied and held pressurized in place until cement hardens.
- Reduction and trialing
  - With the glenoid component and trial humerus component in place there should be no more than half glenoid distance anterior and posterior translation and no dislocation with range of motion.
- Cementing
  - Failure in total shoulder arthroplasty is most commonly due to loosening on the glenoid side.
  - Careful technique with glenoid exposure, reaming, drilling, and cementing is required.
  - Gentle palpation of the inferior/posterior/anterior glenoid edges

will help the surgeon understand the anatomy better for better placement of the glenoid component and peg or keel drill holes, so that the pegs are all in bone.

- Moreover, careful cement technique with applying cement to dry surface and multiple impaction followed by holding the component manually with pressure against that bone until the cement dries are good techniques during shoulder replacement surgery.

- Closure
  - Subscapularis repair insufficiency is a major cause of early failure of total shoulder replacement.
  - Thick nonabsorbable braided suture #2 FiberWire or equivalent is used to repair the subscapularis or lesser tuberosity.
  - First the trial humerus is taken out.
    - Then 4–5 drill holes are placed in the lateral edges around the LT (lesser tuberosity) and FiberWire is passed in those bone tunnels.
    - Then, the actual stem (or stem and head monoblock) is impacted in place with or without cement with the FiberWire suture around the stem, so that each FiberWire start in the lateral edge of LT loops around the prosthesis and exits on the medial edge of the LT.
  - Following this, the sutures are sequentially passed into the subscapularis muscle or at the tendon bone junction in case an osteotomy is used and sequentially tied.
    - The rotator interval is closed and the deltopectoral interval is approximated and the incision is closed in layers with irrigation between layers.

Inverse Shoulder Replacement

- The preoperative planning, positioning, and exposure are similar to standard shoulder replacement.
  - The humerus exposure and preparation is similar as well.
  - For inverse shoulder replacement, a 0 degree of version cut is attempted instead a cut in retroversion.

- Anterior and posterior dislocations are equal in frequency after inverse/reverse arthroplasty.
- After reaming/broaching and putting a trial prosthesis in the humerus, the glenoid is exposed and prepared.

- The glenoid exposure is very slightly different.
  - In cases of inverse shoulder replacements, special attention is paid to isolate and tag the axillary nerve.
  - The inferior capsule exposure is critical to be able to get good visualization of the inferior neck in order to be able to place the baseplate as inferior as possible on the glenoid surface to avoid notching.
  - A Y-shaped inferior glenoid neck retractor is used.
- The guidewire is placed *inferior* to the intersection of the midaxial and midcoronal planes to get the baseplate as inferior as possible.
  - Moreover the guidewire is placed, based on preoperative measurement of glenoid retroversion, in a caudal to cephalad direction in the midcoronal plane to obtain a “smiley face” or preferential reaming of the inferior glenoid, so that the baseplate is pointing toward the floor; this is also to avoid notching.
- The coracoid base is palpated and one of the baseplate screws should attempt to get bone purchase over the cortical bone of the glenoid base.
  - An attempt to place a second screw along the inferior cortical bone stock of the scapula should be made.
  - The Y retractor will elucidate the path of that inferior screw.
- After impaction and bone fixation of the baseplate, the inverse shoulder is trailed after reversal of any paralysis.
  - Anesthesia shoulder blocks are contraindicated in inverse shoulder replacement surgery because they may interfere with appropriate trailing.
- The glenosphere is impacted followed by the humeral cup with the thinnest possible poly and the shoulder is taken through a full range of motion.
  - Any deltoid adhesions should be released and subscapularis should

also be released and an attempt to repair subscapularis should be made.

- If instability is encountered, a larger glenosphere, higher cup, thicker poly can be used.
  - Version of the cup should be carefully checked in relation to the forearm and epicondylar axis and version is corrected if indicated.
- Tares or latissimus transfer should be contemplated for patients with positive hornblower sign and inability to externally rotate an abducted shoulder.

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THE ATHLETE'S SHOULDER

JONATHAN N. WATSON • ARI R. YOUDERIAN

Anatomy and Pathoanatomy

Injuries to the shoulder girdle are very common, especially amongst throwing athletes. There is a wide range of pathologies that occur in the athlete's shoulder, including rotator cuff tears, superior labral anterior–posterior (SLAP) tears, instability, and proximal bicipital tenosynovitis or rupture. In young athletes, proximal humeral epiphysiolysis, or Little League shoulder, has become increasingly common.

The throwing athlete is at risk for shoulder injuries due to the large and repetitive force that is generated during the throwing motion. The mechanism of throwing has been divided into five stages: windup, early cocking, late cocking, acceleration, and deceleration. Throughout this motion, the humeral head is maintained with both static and dynamic stabilizers. Static stability is provided by the capsule and ligaments, and dynamic stability is conferred by the eccentric contraction of the rotator cuff muscles, or concavity-compression principle. The throwing athlete more often presents with microinstability. This occurs secondary to repetitive microtrauma to the anterior capsule with contracture of the posterior capsule and shift of the set point of the humeral head in a posterosuperior direction. This microinstability can lead to further damage, including partial articular-sided rotator cuff tears and SLAP tears.

Burkhart and others have described an entity known as SICK scapula (*s*capula malposition, *i*nferior medial border prominence, *c*oracoid pain and malposition, and dys*k*inesis of scapular movement). The altered position of the scapula leads to increased strain on the posterior capsule structures during the deceleration of throwing. This further results in capsular and muscular tightness leading to glenohumeral internal rotation deficit (GIRD). This constellation of findings is also associated with both internal and external impingement and rotator cuff tears.

Pathology of the long head of the biceps tendon often occurs in concurrence with other lesions in the throwing shoulder and may be difficult to separate from these other entities. The wide range of pathologies include tendinopathy, subluxation, dislocation, and tears of the biceps tendon.

History/Presentation

- Pain and loss of velocity are common presenting symptoms of shoulder pathology, especially in athletes with internal impingement and associated injuries such as SLAP tears and partial thickness rotator cuff tears.
  - The pain is often vague in nature and aggravated by throwing.
  - SLAP tears may be localized to the posterosuperior shoulder with or without biceps radiation.
  - Pain associated with a rotator cuff tear often occurs at night and is accompanied by weakness with radiation into the deltoid.
  - This must be differentiated from cervical spine pathology, which usually has pain from the neck radiating along the scapula and/or into the arm and hand.
- Traumatic events are the main cause of acute shoulder macroinstability.
  - Anterior instability occurs with the arm in abduction and external rotation while posterior instability occurs in a position of adduction and internal rotation.
  - Football linemen also are subject to posterior instability, given the repeated load to a flexed, adducted, internally rotated arm.
  - Age of the patient, chronicity, recurrence of dislocations, presence of bilateral dislocations, and sport are all important when taking an injury history of an instability patient.
- A fall on an outstretched arm is a common cause of rotator cuff tear or labral injury.

    - Weakness or inability to raise the arm is also common with rotator cuff injury.
    - Mechanical symptoms, such as locking or catching, are more frequently associated with superior labral injuries.

Physical Exam

- The physical exam of the shoulder is complex and the examiner must be thorough and organized.
    - The exam can be divided into several sections: inspection, palpation, range of motion, strength, neurovascular, and specific or special maneuvers.
    - The cervical spine must also be examined in all shoulder patients.
    - Core strength (hip abduction, single leg squat) and internal rotation of the hips should be checked in throwing athletes.
    - The elbow should also be assessed due to high levels of concomitant injuries.
- **Cervical spine:** Neck ROM, gait, spasticity/hyperreflexia, Spurling sign, relief of pain with traction
- **Inspection:** Contour and position of the shoulder, muscular asymmetry, Popeye sign, scapular winging
- **Palpation:** AC joint, glenohumeral joint, bicipital groove, Codman point
- **Range of motion:** Passive and active forward elevation as well as in scapular plane, abduction, ER at side, ER and IR with arm abducted to 90 degrees.
    - Total arc of motion and side-to-side differences in throwers to check for GIRD.
    - Observe scapulothoracic motion from behind. Generalized ligamentous laxity in MDI.
- **Strength:** Deltoid, biceps, triceps, rotator cuff, wrist/hand
- **Neurovascular:** R/o brachial plexus/neurovascular injury for acute dislocation

- Thoracic outlet syndrome (Adson sign, Roos test)
- **Instability:** Load and shift, apprehension, relocation, sulcus
- **Rotator cuff/Impingement:** Neer, Hawkins, empty can, belly press, lift-off, external rotation lag sign, Hornblower's, scapular retraction
- **Biceps:** Speed, Yerguson
- **SLAP:** Obrien's, Crank, resisted supination and ER, biceps load I & II, anterior slide, dynamic labral shear

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Imaging

- Radiographs: Standard AP, scapular Y, and axillary lateral radiographs are obtained in most cases.
  - The AP view, or Grashey view, is tilted 30–45 degrees from the sagittal plane of the body in order to obtain a view that is parallel to the glenohumeral joint.
    - The AP view is most useful for examining calcific tendinitis, glenohumeral joint space narrowing, cysts, or osteophytes and proximal migration of the humeral head (normal acromiohumeral distance is 7 mm).
    - Widening of the proximal humeral physis can be seen with Little League shoulder with comparison to the opposite side.
    - An outlet view can be considered to determine acromial morphology in cases of possible rotator cuff tear secondary to impingement.
  - In cases of dislocation or instability, the scapular Y and axillary lateral are obtained to determine the position of the humeral head in the glenoid.
    - In certain instances of acute dislocation and inability to obtain an axillary view, a Velpeau lateral can be obtained. The patient leans backward ~30 degrees and the beam is directed from superiorly.
    - The West point view is used to view the glenoid rim and check for bony Bankart lesions. It is obtained by placing the patient prone with the arm in 90 degrees of abduction and neutral

rotation. The cassette is placed at the superior aspect of the shoulder and the beam directed from inferior and projected cephalad 25 degrees from the horizontal and medially 25 degrees.

    - The Stryker notch view is used for Hill–Sachs lesions. In the supine position, the palm of the hand is placed on top of the head with the shoulder in 90 degrees of forward flexion and neutral abduction with the cassette posterior to the shoulder.

- CT is used most often in the shoulder to characterize bony Bankart lesions, glenoid bone loss and morphology, and sizing of the Hill–Sachs lesion.
- Ultrasound is a noninvasive, inexpensive method of diagnosing rotator cuff tears; however, its utility is operator dependent and has limited ability to diagnose concomitant pathologies.
- MRI is commonly used to diagnose rotator cuff and labral pathology.
  - MRI can confirm the tear pattern, extent of retraction, and number of tendons involved.
  - Fatty infiltration and muscular atrophy is assessed using a modified Goutallier grading system for determining tear reparability and prognosis.
  - Intra-articular contrast is frequently used for determining the extent of partial articular-sided rotator cuff tears and for improved imaging of labral pathology.
  - The use of ABER (abduction external rotation sequences) is often helpful in MRI of the overhead athlete.
- Arthroscopy is still considered the gold standard for diagnosis of labral pathology.

Conservative Treatment

- As with the majority of other orthopedic conditions, conservative management should be the initial method of treatment. Modification of activity, ice, anti-inflammatory medications, and physical therapy are the common modalities utilized.
  - Cessation of throwing is the mainstay of treatment for Little League

shoulder.

- Nonsteroidal anti-inflammatory drugs (NSAIDs) are the most commonly prescribed medications.
- The use of corticosteroid injections can also be used for both diagnostic and therapeutic purposes.
- Physical therapy should focus on stretching as well as strengthening exercises addressing both the shoulder and scapula.
- Those with GIRD should focus on stretching of the pectoralis minor as well as the sleeper stretch for posterior capsular tightness.
- Core strengthening and focus on the kinetic chain is advocated for the throwing athlete.
  - Strengthening of the scapular stabilizers and rotator cuff is necessary as well.
- A graduated program of return to throwing or other activities should be instituted following a course of therapy.

- Closed reduction is the immediate treatment of acute shoulder instability. Numerous techniques have been described; however, superiority of one technique over another has not been shown.
  - Often, adequate sedation is required with both pre- and postreduction imaging to assess for fracture and adequate reduction.
  - After reduction, patient is treated in a sling for comfort over a short period of time followed by progressive range of motion and strengthening exercises.

Operative Indications

- Failure of nonoperative management
- Acute, full-thickness rotator cuff tear in a young or symptomatic patient
- Partial-thickness rotator cuff tear with >50% tear or >6 mm of the footprint exposed
- Recurrent shoulder dislocation/subluxation

- Debridement of type I, III SLAP lesions, repair of types II, IV
- Bony instability procedure needed for >25% glenoid bone loss, inverted pear morphology, engaging Hill–Sachs lesion, humeral avulsion of glenohumeral ligament (HAGL)

Surgical Technique

- First, general anesthesia and/or scalene block is performed.
  - Patient is placed into either the beach chair or lateral decubitus position based on surgeon preference.
  - In the beach chair position, care should be taken to ensure neutral cervical flexion/extension and rotation, as well as padding of the nonoperative extremities.
    - An arm-holding device may be used to assist intraoperatively.
  - In the lateral decubitus position, the patient is often placed onto a beanbag for positioning with the down leg padded to avoid a peroneal nerve palsy.
  - Traction is placed on the operative arm to assist in joint distraction, especially for instability procedures.
    - Standard landmarks are marked prior to incision.
    - Joint insufflation can be performed prior to portal placement to aid in joint distraction.
    - There are a multitude of portals available as described below, each of which has advantages and indications, depending on pathology.

Portals

- **Posterior portal:** 2 cm inferior and 2 cm lateral to posterolateral corner of acromion, most common entry and viewing portal
- **Anterosuperior portal:** 2 cm lateral to coracoid and 1 cm inferior to anterior acromion
- **Anterolateral portal:** just off anterolateral corner of acromion 3–4 mm.

- Utilized for anchor placement in superior glenoid 11–1 o'clock for SLAP or viewing portal for instability repair

- **Anteroinferior portal:** lateral to coracoid, above subscap adjacent to humeral head
- **Transsubscap portal:** used for Bankart repair
- **Lateral portal:** 3–4 cm lateral to acromial edge in line with intersection of posterior AC joint w/ supraclavicular fossa
- **Posterior subacromial:** 1.5 cm inferior, 1.5 cm medial to posterolateral corner of acromion
- **Anterior subacromial:** 1.5 cm inferior to anterolateral corner of acromion
- **Lateral accessory acromion:** immediately adjacent to lateral border of acromion
- **Portal of Wilmington:** 1 cm lateral, 1 cm anterior to posterolateral corner of acromion. Insertion of suture anchors for posterior SLAP.
- **Neviaser portal:** 1 cm medial to medial border of acromion, 1 cm posterior to clavicle, 1 cm anterior to spine of scapula
- **High posteromedial portal:** 2 cm medial to posterior portal, 1 cm inferior to spine of scapula
- **Medial accessory posterior portal:** 2 cm medial to posterior portal
- **Low posterolateral portal:** 4–5 cm lateral to posterior portal, 5–6 cm inferior to posterolateral corner of acromion
- **Low posteromedial portal:** 2 cm medial, 2 cm inferior to posterior portal

Key Points

- Bankart: Mobilize capsulolabral tissue and free from glenoid prior to repair.
  - Make sure to reach 5:30 position prior to anchor placement.
  - Place anchors on glenoid face, tie knots on capsular side.
- Spinal needle/marker suture placed through articular rotator cuff tear for bursal evaluation; bursal evaluation is done later during subacromial phase of the surgery

- Debridement of rotator cuff tears preferred to repair in throwing athletes
- No research showing superiority in clinical outcomes of rotator cuff repair techniques (single row vs. double row, transosseous equivalent)
- Beware of anatomic variants (Buford complex, sublabral foramen) when planning SLAP repair, limit anterosuperior repair
- Biceps tenodesis in throwing athletes for SLAP tears is still controversial
- Older literature reports ~95% success rate for open instability procedures.
  - While arthroscopic repair was previously thought to have high recurrence rates, with the advent of newer technology and technique arthroscopic results approach those of open, with 90–96% success rates.
- Recent studies have shown up to 70–80% return to play rates for SLAP repairs
- Research has shown very poor return to play rates for repair of rotator cuff repairs (8%); however, improved rates were seen with debridement alone (55%).

Complications

- Infection
- Arthrofibrosis
- Rerupture of rotator cuff repair
- Shoulder instability surgery: recurrence of instability, subscapularis rupture, arthrosis, neurovascular injury, hardware failure
- Chondrolysis related to anchor placement for labral repair
- Little League shoulder: slippage of the proximal humeral physis

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ELBOW DISLOCATION

DAVID D. SAVIN • ARI R. YOUDERIAN

Anatomy and Pathoanatomy

The elbow is a synovial hinge joint, with articulations between the radius, ulna, and humerus. The elbow is intrinsically stable due to a combination of the bony contour, ligamentous stability, strong capsule, and a multitude of muscles.

Despite being an inherently stable joint, the elbow is the second most common joint to be dislocated, only surpassed by shoulder dislocations. Its incidence is 6–13/100,000, with >50% being from a sport-related injury. This injury is much more common among adolescent and young adult age groups. Most injuries have a high-energy mechanism, with >90% of dislocations being in the posterior direction.

An elbow dislocation is typically associated with complete disruption of the capsuloligamentous constraints, often with lateral constraints giving away first, including the lateral collateral ligament. The medial collateral ligament is typically last to fail. Elbow dislocations can be described as simple or complex. Complex dislocations have an associated elbow fracture. They can be further classified by their relationship between the olecranon and humerus, with the most common location being posterolateral dislocation.

History/Presentation

- Patients with an acute elbow dislocation typically will present with a history of falling on an outstretched hand.
- However, the mechanism is usually more complex and likely includes a combination of the following forces: valgus, supination,

and axial load.

- Patients may also present in the setting of multiple traumatic injuries.
- It is always important to denote the dominance of the affected arm.

Physical Exam

- Trauma patients should be initially managed per the ATLS protocol.
- Once clinically stable, the orthopedic surgeon can evaluate the elbow.
- The following exam will allow complete assessment of the elbow injury:
  - Upon visual inspection, the deformity is often obvious.
    - The relationship of the tip of the olecranon to the medial and lateral epicondyle with comparison to the contralateral side can help confirm diagnosis.
    - Evaluate skin for soft tissue injury or impending soft tissue injury.
  - Evaluation of the distal forearm should include assessment of the distal radioulnar joint and interosseous membrane for pain or instability.
  - The distal neurovascular status should be well documented.
    - The ulnar and median nerves are more commonly compromised than the radial nerve.
    - Radial nerve symptoms may be associated with radial head fracture or Monteggia fracture.
    - The presence of a pulse may not rule out significant vascular injury as there is significant collateral circulation.
  - Exam should also focus on shoulder, humerus, forearm, wrist, and hand for associated injuries.

Imaging

- Conventional radiographs with standard anterior–posterior and lateral radiographs will help characterize the dislocation pattern.
- Computed tomography (CT) with 3D reconstruction will be helpful for complex fracture dislocations and for postreduction operative planning of associated elbow fractures. This should not be performed prior to reduction.
- As standard practice, conventional radiographs should include the joint above and below.
- Magnetic resonance imaging (MRI) has little use with acute elbow dislocations; however, in an unstable elbow after reduction, an MRI can be helpful to assess injury pattern.

Acute Management

- Reduction can be attempted after the patient has been stabilized and thorough exam has been completed.
  - Closed reduction should be performed with some form of sedation/anesthesia to achieve adequate muscle relaxation/analgesia.
  - Late reductions are more difficult due to significant muscle spasm and swelling.
- *Closed reduction* for posterior/posterolateral dislocation:
  - A clunk is often felt when successfully reduced.
  - Two methods are described below:
    - Supine:
      - The patient is placed supine with arm overhead.
      - The coronoid should be cleared from the distal humerus with hypersupination.
      - Reduction should be performed with a valgus stress, extension of the elbow with a manual distal force on the olecranon process.
    - Prone:
      - The patient is placed prone with elbow elevated and flexed

over side of bed.

    - The elbow should be extended with gentle longitudinal traction on the arm.
    - The coronoid should be manipulated with the thumb to clear the trochlea.
  - After reduction, the patient should be reexamined, initially focusing on neurovascular exam.
    - An acute change in neurovascular exam is rare but if present, necessitates early surgical exploration.
    - The elbow should then be assessed for instability while the patient is sedated. Safe range of motion (ROM) is determined during this exam.
- *Postreduction assessment*
  - While in pronation, the elbow should be assessed for varus, valgus, and rotatory instability.
  - Varus and valgus instability should be assessed at full extension and at 30 degrees of flexion.
  - Rotatory instability should be evaluated with a pivot shift test, which is performed on a supine patient, forearm supinated and a valgus stress is applied while flexing the elbow.
    - This should not be performed on a nonsedated patient.
- Postreduction elbow radiographs should also be obtained. If there is concern for a fracture, CT scan with 3D reconstruction can help characterize the fracture pattern.
- In-office fluoroscopic exam is also a helpful adjunct to assess stability and guide treatment.
  - Full ROM of the elbow often can be attempted under fluoroscopy at the first office visit 1–2 wks after the dislocation event.

Conservative Management

- Most simple reductions can be managed nonoperatively.
  - If the reduced elbow is completely stable during the postreduction

stability assessment, it can be immobilized in a sling or a long arm posterior mold splint.

  - Supervised early ROM should start 7–10 d after injury.
- If there is extension instability, the patient can be transitioned to a hinged elbow brace with forearm in pronation and elbow at 90 degrees of flexion for 2–3 wks.
  - Some surgeons prefer to lock them at ~10 degrees more flexed than the point of instability.
  - Immobilization for longer than 3 wks is associated with contractures and decreased ROM.

Operative Indication

- Immediate surgery is rarely indicated in elbow dislocations.
  - Acute surgical indications include inability to close reduce, associated compartment syndrome, new neurovascular compromise after reduction, acute neurovascular injury associated with the dislocation and open injuries.
- Elbows that remain unstable after reduction despite being placed in flexion and pronation typically have extensive soft tissue injury, including disruption of the collateral ligaments, common extensor/flexor muscle origins, and capsular injury.
  - Surgery should be performed to improve elbow stability.
  - The elbow typically becomes stable after reconstruction or repair of the lateral ulnar collateral ligament (LUCL).
  - If it remains unstable despite LUCL repair, the ulnar collateral ligament should also be repaired.
  - Following this, the flexor/extensor muscle origins should be repaired to enhance stability.
  - When indicated, early surgical intervention is preferred due to a lower risk of postoperative stiffness and heterotopic ossification.

Fracture Dislocation

- An elbow dislocation with an associated fracture is described as a complex elbow dislocation.
- Fractures typically involve the radial head, coronoid, olecranon, and/or distal humerus.
  - One described fracture pattern includes the terrible triad injury of the elbow.
    - This is a traumatic posterior lateral dislocation with associated MCL tear, radial head, and coronoid fracture.
  - The mechanism of injury is similar to simple elbow dislocations, but often with higher axial, valgus, and rotational forces.
  - Anteromedial fracture dislocation is another described pattern.
    - It is less common than the terrible triad and is often seen with a larger coronoid fracture but no associated radial head fracture.
- The majority of these complex dislocations are unstable and require surgery.
  - Different fracture patterns have specific indications for surgery, but generally a displaced fracture or an unstable elbow is an indication for surgery.
  - Acutely, the elbow should be reduced and assessed for stability.
  - Unstable fracture dislocations require open reduction and internal fixation of the fracture and repair or reconstruction of the ligamentous injury.
  - A preoperative CT scan with 3D reconstruction can be helpful to visualize complex fracture patterns.
  - If the elbow remains unstable despite ORIF and soft tissue repair, a dynamic external fixator can stabilize the elbow while allowing early ROM.

Complications

- Posttraumatic stiffness, often 10–15-degree lack of full extension
- Chronic posterolateral instability
- Heterotopic bone formation

- Neurologic compromise—usually transient, however, permanent ulnar nerve palsy can be seen
- Posttraumatic arthritis

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ELBOW BURSITIS AND TENDONITIS

HANY EL-RASHIDY • VAMSY BOBBA

Elbow Anatomy and Pathoanatomy

A hinge joint comprises the humerus, ulna, and radius. The most proximal extent of the ulna ends as the bony olecranon process. Superficial to the olecranon is the olecranon bursa, a fluid-filled sac, which reduces friction between soft tissue layers. Surrounding the bursa are the tendons of several muscle groups attaching near the joint. The lateral aspect of the joint includes the extensors (i.e., ECRB), while the medial aspect contains the flexors (i.e., FCR). The anatomy of the elbow joint allows for flexion/extension as well as rotation. Osseous stability is conferred via the medial and lateral ligamentous complexes. The medial complex, or ulnar collateral ligament (UCL), provides valgus stability. The UCL is composed of anterior, posterior, and transverse bands, with the anterior band providing the greatest stability. The lateral collateral ligament complex provides varus and rotational stability, this comprises radial and ulnar lateral collateral ligaments. The annular ligament encompasses the radial head and, along with the radial collateral, assists with varus stability.

Overuse, poor conditioning, or direct trauma to the elbow joint can lead to bursitis, inflammation, and damaged tissue. This damage can cause microtearing of the muscles at their origins and can lead to a pathologic healing response termed angiofibroblastic tendinosis.

- **Epicondylitis**
  - A process of tendon degeneration and incomplete repair (not a true inflammation).

  - Lateral epicondylitis (called tennis elbow) involves the extensor tendon origin and medial epicondylitis (golfer's elbow) involves the common flexor origin.
  - Lateral epicondylitis occurs more frequently than medial epicondylitis with a ratio of between 4 and 7:1.
- **Olecranon bursitis**
  - Can result from trauma or repetitive activity (i.e., resting the elbow on a hard surface).
  - Accounts for 0.01–0.1% of hospital admissions.
  - Common in males aged 30–60.
- **Triceps tendinitis**
  - Occurs almost exclusively in men, usually in the 4th decade of life, and especially in individuals who are subjected to repetitive extension activities (i.e., throwing athletes).

History/Presentation

- **Medial and lateral epicondylitis**
  - Although there may be a precipitating injury, more commonly, the pain is insidious in onset.
  - Patients report weakness in grip strength and difficulty with carrying objects.
  - Athletes, musicians, and carpenters are at particular risk.
  - Complaints include tenderness over the forearm flexors/extensors, painful/limited ROM at the wrist and elbow, decreased grip strength, and swelling.
  - Pain can be exacerbated during throwing and other sporting activity.
- **Olecranon bursitis**
  - Most commonly due to posttraumatic injury (direct fall on the elbow) but can also develop insidiously.
  - Occurs in association with gout (precipitation of crystals within the

bursa) and rheumatoid arthritis.

- Triceps tendinitis
  - Occurs from overload of the triceps insertion as a result of forceful activity required throughout the acceleration phase to the release phase of arm extension.

Differential Diagnosis

- **Lateral epicondylitis**
  - Radial tunnel and posterior interosseous nerve (PIN) syndrome—pain with resisted supination or with resisted long-finger extension
  - Osteochondritis dissecans of the capitellum
  - Radiocapitellar arthrosis
  - Cervical radiculopathy
- **Medial epicondylitis**
  - Ulnar neuropathy—positive Tinel sign (valgus stress on elbow produces parasthesias along ring and small fingers), elbow flexion test—maximum elbow flexion, forearm in pronation, wrist in extension
  - UCL attenuation with instability—evaluate with passive valgus stress of elbow between 20° and 90° (milking maneuver)
- **Triceps tendinitis**
  - Posterior impingement—pain with isometric active extension short of full extension
  - Olecranon bursitis—direct tenderness over bursa

Physical Exam

- **Lateral epicondylitis**
  - Always examine cervical spine, followed by the full extremity.
  - Tenderness to palpation at or just distal to lateral epicondyle, over

extensor origin.

  - Pain elicited by resisted wrist extension with the elbow in full extension and forearm in pronation or by maximal wrist extension.
  - Compare grip strength with contralateral side. Studies indicate grip strength to be 50% of healthy arm during extension.

- **Medial epicondylitis**
  - Pain localized to the medial epicondyle or over flexor–pronator mass.
  - Pain during resisted pronation and resisted wrist flexion are good indicators, with the former being more sensitive.
- **Olecranon bursitis**
  - Swelling and tenderness to palpation over olecranon.
  - Palpation may reveal painless or painful erythematous swelling.
    - Associated cellulitis may be present.
  - Chronic bursitis can present with multiple small fluid-filled lumps. Infectious cases will manifest with pain, warmth, and erythema.
    - 50% of individuals present with fever.
    - Erythema manifests in 63–100% of infected bursitis and in 25% of patients with nonseptic bursitis.
- **Triceps tendinitis**
  - Posterior elbow discomfort at triceps insertion.
  - May exhibit direct and/or indirect tenderness.
  - Pain is exacerbated during forced elbow extension.

IMAGING

- **Lateral epicondylitis**
  - XR: May show calcifications in soft tissues surrounding lateral epicondyle.
  - MRI: Tendon degeneration and tear in ECRB; T1- and T2-weighted

images demonstrate increased signal around the lateral epicondyle.
    - May also reveal edema and thickening of the extensor origin.
- **Medial epicondylitis**
  - XR: May show calcifications around medial epicondyle; not generally utilized.
  - MRI: Increased signal on T1- and T2-weighted images, consistent with thickening of common flexor tendon origin.
    - Some patients may have thinning of common flexor tendon origin with intense fluid signals in T2-weighted images.
- **Olecranon bursitis**
  - XR: Not usually indicated unless secondary to trauma, in which case, rule out olecranon fracture.
  - MRI: Look for abscesses or osteomyelitis
- **Triceps tendinitis**
  - XR: Look for a triceps/olecranon traction spur or loose bodies.
  - MRI: Rarely indicated, but may reveal inflammatory changes

Prevention

- Adequate training on technique and proper equipment selection, rest from overexertion.

Nonoperative Management

- **Lateral epicondylitis**
  - Active rest, NSAIDS
  - Counterforce bracing (reduces load at lateral epicondyle)
  - Cortisone injection
  - Platelet-rich plasma (cytokines, such as VEGF/PDGF, may aid in tendon healing)

- Patient education (ensure proper techniques during athletic activity)
- Physical therapy: stretching, strength conditioning, deep friction massage, electrical stimulation, ultrasound, and iontophoresis

- **Medial epicondylitis**
  - Initially, cessation of offending activity
  - NSAIDs
  - Counterforce brace (if compressive neuropathies absent), cortisone injection, iontophoresis, and electrical stimulation
    - Once pain improves, follow up with physical therapy for range of motion and strength conditioning.
    - May return to activity when symptom-free range of motion is achieved.
- **Olecranon bursitis**
  - Acute aseptic bursitis resolves without medical treatment.
  - In patients with pain and swelling, employ rest, ice, NSAIDS, analgesics, compression wrap for swelling and effusion.
  - Aspiration of bursa and cortisone injection can afford relief, but rate of recurrence is high.
  - In infected cases, appropriate antibiotic therapy, such as penicillinase-resistant penicillin is indicated.
    - Some may aspirate fluid using 18- or 20-gauge needle.
    - If so, send for fluid analysis (cell count, Gram stain, culture and sensitivity, crystals).
- **Triceps tendinitis**
  - Rest from repetitive forceful elbow extension, NSAIDS, splint in 45° elbow flexion.
  - Cortisone injection into tendon insertion is contraindicated.
  - Physical therapy, including ultrasound may provide temporary relief.
  - Conservative therapy has higher success rate in absence of olecranon traction spur.

Operative Indications

- Patients who are recalcitrant to conservative treatment.
- For epicondylitis, recommendations are to continue a conservative course for a minimum of 6 mos.
- Young, athletic individuals or those individuals whose occupations require repetitive activities, may elect a more aggressive approach.

Contraindications

- Acute infection
- Noncompliant individuals
- Limited ROM

Surgical Technique

- **Lateral epicondylitis—arthroscopic**
  - Pre-op area
    - Take a history and repeat physical exam in pre-op.
    - Be aware of anesthesia plan, antibiotics.
    - Obtain consent and mark operative site.
  - Positioning
    - Lateral or prone, affected extremity on bolster with tourniquet
  - Procedure
    - After introducing normal saline into the elbow joint via soft spot lateral portal, a proximal anteromedial portal is created to inspect the joint.
    - The lateral capsule is evaluated for capsular tears, synovial thickening, extension of the annular ligament, or radiocapitellar chondromalacia.
  - ECRB resection
    - A proximal anterolateral portal is created and a shaver is

introduced to resect part of the lateral capsule to reveal the common extensor tendon.

- The ECRB tendon lies between the common extensor tendon and the lateral capsule.
- Using either a shaver or monopolar radiofrequency device, ablate the tendinosis tissue with complete resection of the ECRB origin at the lateral humerus.

- Final steps
  - The joint is thoroughly irrigated and the portal sites are routinely closed. A soft dressing is applied.

- Lateral epicondylitis (Open)
  - Positioning
    - Supine, affected extremity on attached arm board with tourniquet placed around arm.
  - Procedure
    - A 4-cm curvilinear incision is made anteromedial to the lateral epicondyle.
    - Subcutaneous tissues are separated until the deep fascia of the extensor tendons is exposed.
    - The interval between ECRL and EDC is identified and split superficially to a depth of 2–3 mm.
    - The ECRL is separated from underlying ECRB using scalpel dissection and retracted anteriorly.
    - Pathologic tissue, of a dull, gray appearance, is excised.
    - Vascular healing is promoted by drilling the lateral epicondyle using a 0.062 Kirschner wire or roughening with a rongeur.
    - Reattachment of ECRB is at the surgeon's discretion and is not required.
    - The ECRL and EDC aponeurosis are reapproximated using running no. 1 absorbable suture.
  - Final steps
    - Subcutaneous tissues and skin are routinely closed.

    - A posterior splint is applied with the elbow in 90º of flexion.
- **Medial epicondylitis (open)**
  - Positioning and prep
    - Same as lateral
  - Procedure
    - A curvilinear incision is made starting 2 cm proximal and extending 3–4 cm distal to the medial epicondyle.
    - The incision should follow the epicondylar groove (posterior to the epicondyle) in order to avoid iatrogenic injury to the medial antebrachial cutaneous nerve and allow access to ulnar nerve.
    - Dissect to reveal flexor carpi ulnaris and then proceed anterolaterally to expose common flexor origin.
    - A longitudinal incision is made in the common flexor origin starting at the medial epicondyle and extending distally 4 cm.
    - The incision is situated between the pronator teres and FCR. In an elliptical fashion, any dull, gray abnormal tissue is identified and excised.
    - Using a 0.062 K-wire, multiple holes are drilled into the cortical bone distal to the medial epicondyle to stimulate healing.
    - The elliptical tendon defect is closed with no. 1 absorbable suture, followed by subcutaneous closure.
  - Final steps
    - Skin is closed with a running subcutaneous stitch with 3–0 absorbable suture.
    - A posterior splint is applied with the elbow in 90º of flexion.
- **Olecranon bursitis (arthroscopic):** Indicated only if NO olecranon spur, otherwise open treatment is recommended.
  - Positioning
    - Lateral or semilateral with beanbag, allow arm to rest across chest for posterior exposure
    - Tourniquet

- Procedure
  - Dual portals are utilized to fully visualize bursa, which is completely excised.
  - Care is taken with the instruments in the medial aspect of the bursa as the ulnar nerve courses medial to bursal extension.
- Final steps
  - Following excision, portal sites are left open and compression dressing is applied.

- **Olecranon bursitis (open):** Indicated when spur is to be removed or if bursa access is limited.
  - Positioning
    - Lateral or semilateral with beanbag or bump underneath trunk, allowing arm to rest across chest for posterior exposure to elbow
    - Tourniquet
  - Procedure
    - Longitudinal incision medial to midline is utilized.
    - Bursal tissue is completely excised.
    - Subcutaneous dissection is limited around bursa to avoid possible disruption of blood supply of skin.
  - Final steps
    - Incision routinely closed, elbow immobilized at 45 degrees of flexion in splint with compressive dressing.
- **Triceps tendonitis**
  - Positioning
    - Prone, affected extremity on attached arm board with tourniquet.
  - Procedure
    - After routine prep and draping, 4–5 cm longitudinal incision is made ~1.5 cm lateral to the olecranon, starting 2 cm distal to the tip and extending 2–3 cm proximally.
    - Subcutaneous dissection may reveal olecranon bursitis, which is

excised.

- Extensor mechanism is then exposed and the midaxis of the olecranon is identified.
- Exposure of subperiosteal triceps spur is gained via a longitudinal incision over midpoint of olecranon spur.
- Using a no. 64 beaver blade, the exposure is extended medially and laterally.
- After adequate exposure of the spur, the triceps insertion onto the remaining spur is dissected off the spur and the olecranon.
- After complete spur exposure, a rongeur is utilized to remove the spur and a portion of the posterior olecranon tip.
  - May use 1 or 2 suture anchors, placed symmetrically in the defect and a locking suture is placed through the triceps, passing the suture back through to the defect site. An alternative is to utilize bone tunnels.
  - The knot is tied off at the tendon–bone interface to minimize prominence.
  - An epitendinous triceps repair is then carried out via a buried, running 4–0 Mersilene suture to cover the prior knots and complete the repair.

- Final steps
  - Wound is thoroughly irrigated and subcutaneous closure is carried out.
  - A splint with the elbow at 45° flexion is applied.

Postoperative Rehab and Expectations

- **Lateral epicondylitis**
  - Patients remain in splint for 1 wk to allow wound healing.
  - Afterward, patients are encouraged to rehab by working on PROM and AROM at the elbow and wrist, stretching and strengthening as tolerated.
  - Typically, return to light activities is permitted after 2 wks and to

sports after 6 wks.

- **Medial epicondylitis**
  - Posterior splint is removed 1 wk postsurgery, at which point physical therapy for range of motion of elbow and wrist is started.
  - Strength conditioning is started 4–6 wks postsurgery with a counterforce brace worn for therapy and activities of daily living.
  - Patient is cleared without restrictions at 4–5 mos post-op.
- **Olecranon bursitis**
  - Compressive dressing and splint are utilized for 1–2 wks.
  - Routine activity resumed afterward.
- **Triceps tendinitis**
  - Splint/cast is utilized for 3 wks, followed by 3 wks of passive range of motion rehab.
  - Active range of motion therapy is started 6 wks post-op and continued with strengthening at 3 mos.
  - Full recovery is typically achieved by 6 mos.
- **Most important**
  - Explain to the patient that the rehabilitation process is long and difficult.
  - Stress the importance of compliance with restrictions to achieve successful results.

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ELBOW ARTHRITIS

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Introduction

Elbow arthritis, as with degenerative disease in other joints, leads to pain, stiffness, instability, mechanical symptoms, and deformity. Range of motion of the elbow required for activities of daily living requires 50 degrees of pronation and supination, as well as an arc of flexion/extension of ~100 degrees.

- Unlike in hip and knee arthritis, *rheumatoid arthritis (RA)* is the **most prevalent type** of elbow arthritis. Anywhere between 20% and 70% of RA patients have involvement of the elbow. Chronic inflammation and synovitis lead to ligament attenuation, periarticular osteopenia, symmetric joint space narrowing, and joint contracture. The Mayo classification system is used for stratification of elbow joint involvement in RA patients (Table 3.1).
- The **next most common form** is *posttraumatic elbow arthritis,* which is typically seen in active young patients. The articular injury can involve a specific area of the elbow, such as the radiocapitellar articulation or be isolated to the distal humerus, or can involve the entire joint. Treatment is dictated by the area of involvement. Careful evaluation of patients with posttraumatic elbow arthritis should include a history of prior treatment, surgery, hardware, and infection.
- **Less common causes** of arthritis of the elbow include chronic ligamentous insufficiency (such as MUCL deficiency), osteochondritis dissecans, septic arthritis, crystalline arthropathy, hemophilia, and primary osteoarthritis.
- *Primary osteoarthritis* of the elbow is seen in ~1–2% of the

population. It is typically seen in middle-age male patients with a history of manual labor, heavy weight lifting, or throwing sports. Primary osteoarthritis has the tendency to have relative preservation of both the articular cartilage and joint space. Joint contracture and osteophyte formation can lead to a mechanical block of motion. Early in the disease, patients will report pain and stiffness with extremes of motion while in later stages patients will have pain throughout the entire arc of motion. Recently, Rettig et al. developed a radiographic classification system for osteoarthritis of the elbow (Table 3.2).

As with arthritis of other major joints, initial treatment consists of conservative management involving NSAIDS, disease-modifying antirheumatic drugs (DMARDs) in the case of RA, physical therapy, activity modification, splinting, and cortisone injections. Once nonoperative management fails, surgical options include synovectomy, arthroscopic debridement with capsular release, ulnohumeral distraction interposition arthroplasty, hemiarthroplasty, and total elbow arthroplasty. When considering surgical options, patient age, etiology, activity level, and severity of symptoms are paramount. In early-stage disease, options include synovectomy in the case of RA, and arthroscopic/open debridement with capsular release. Interpositional arthroplasty remains an option for patients with more severe disease who are unwilling to accept the restrictions of total elbow arthroplasty (carrying limit of 10–15 lb). Young patients with debilitating symptoms are a difficult challenge, as total elbow arthroplasty is typically reserved for patients >65 yrs of age and carries significant restrictions.

Table 3.1 Mayo Radiographic Classification System for RA Patients

Grade I—Synovitis, normal-appearing joint, mild to moderate osteopenia
Grade II—Joint space narrowing, but maintenance of the subchondral architecture
Grade III—Complete loss of joint space
Grade IV—Severe joint destruction
Grade V—Bony ankylosis of ulnohumeral joint

Table 3.2 Rettig Classification for Osteoarthritis

Class I—Degenerative changes at ulnotrochlear joint, but sparing of radiocapitellar joint
Class II—Mild joint space narrowing of radiocapitellar joint
Class III—Radial head subluxation

The longest average survivorship for total elbow arthroplasty is in rheumatoid patients with survivorship rates >90% at 15-yr follow-up.

Complications of total elbow arthroplasty include infection, aseptic loosening, osteolysis, triceps insufficiency, periprosthetic fracture, ulnar nerve irritation, and wound problems.

History/Presentation

- Patients with RA typically complain of pain throughout the entire arc of motion.
  - It is important to ascertain what other joints are involved, as well as if there is bilateral involvement, as this will significantly impact the patients' ability to perform activities of daily living.
  - Synovitis, as well as periarticular joint destruction, will lead to instability in the later stages of disease.
  - Patients with severe disease can develop gross coronal plane instability leading to a flail elbow.
- Posttraumatic arthritis can occur after any traumatic event to the elbow.
  - It is important to elicit the mechanism of injury, type of fracture, presence of instability, treatment, surgical approach, hardware in place, soft tissue complications, and infection.
  - As with all types of elbow arthritis, a history of ulnar nerve irritation may be present.
    - This is associated with the presence of preoperative loss of flexion <100 degrees or loss of extension >30 degrees and will dictate the need for an ulnar nerve transposition at the time of surgery.
- Primary osteoarthritis is seen more commonly in males, at a ratio of 4:1.
  - It is more often associated with the dominant hand, a history of manual labor, heavy weight lifting, or those participating in throwing sports.
  - Patients typically report pain while carrying heavy objects with the

elbow extended at the patients' side.

- Initially, patients will complain of pain and stiffness with extremes of motion (loss of extension the most common presenting finding) while in later stages of the disease patients will have pain throughout the entire arc of motion.
    - This is important when selecting the appropriate surgical option.

Physical Exam

- The patient's elbow should be inspected for deformity, previous surgical scars, presence of infection and soft tissue compromise, and the presence of skin grafts or flaps.
- The range of motion in flexion, extension, pronation, and supination should be documented, as well as the presence of crepitus or mechanical locking.
- Pronation/supination pain, crepitus, or weakness indicates radiocapitellar joint pathology while flexion/extension pain, crepitus, or weakness indicates ulnotrochlear pathology.
- Ligamentous incompetence may be seen, specifically in RA and posttraumatic arthritis.
- Posterolateral rotatory instability and the integrity of the lateral ulnar collateral ligament can be evaluated by the lateral pivot shift test, apprehension test, chair rise test, push-up test, or the table-top relocation test.
- Evaluation of varus posteromedial instability and evaluation of the medial collateral ligament (anterior oblique component most significant stabilizer to valgus stress) can involve the valgus stress test, moving valgus stress test, or milking maneuver.
- A thorough neurovascular exam should be performed with careful attention paid to the ulnar nerve distally, as ulnar neuropathy is a common finding in patients with arthritis of the elbow and a flexion contracture.

Imaging

- Initial imaging should consist of AP, lateral, and oblique views of the elbow at 90 degrees of flexion.
  - In RA patients diffuse osteopenia, periarticular erosions, and symmetric joint space narrowing are common findings.
  - In primary osteoarthritis, preservation of the radiocapitellar and ulnohumeral joint spaces is typically seen.
  - Several classification systems separated by etiology exist, including the Mayo radiographic classification system for RA patients (Table 1) and Rettig classification for osteoarthritis (Table 2).
- A CT scan may also be considered as it can be useful to identify loose bodies and osteophytes near the ulnar nerve, the olecranon fossa, radial fossa, and coronoid fossa.
  - CT scans have been shown to be more effective than plain radiographs in determining the cause of elbow stiffness.
  - CT scans with 3D reconstructions are gaining popularity for their usefulness in preoperative planning.
- MRI studies are typically not necessary in the evaluation of elbow arthritis.
- Additional testing such as an EMG should also be considered in patients where peripheral neuropathies are a concern, especially involving the ulnar nerve.

Lab Studies

- If infection is being considered, a CBC with differential, ESR, and CRP are ordered.
- Contingent on lab results, a follow-up elbow aspiration should be done to determine the presence or absence of infection. Aspirate is sent for cultures, Gram stain, cell count and crystals.

Conservative Treatment

- A trial of nonoperative management is the first line of treatment for arthritis of the elbow and can be effective in patients with minimal to moderate disease.

- DMARDs can slow the progressive nature of joint destruction seen in RA patients. Other options include rest, physical therapy, activity modification, static progressive splinting, dynamic hinged splinting, NSAIDs, and cortisone injections.
- No conclusive evidence is available regarding the effectiveness of sodium hyaluronate in the treatment of elbow arthritis, nor is it approved for use in the elbow by the U.S. Food and Drug Administration.

Operative Indications

- Synovectomy (arthroscopic or open)
  - Early RA disease states, Mayo grade I or II
  - Proven to relieve swelling and pain, but has not been shown to slow natural history of disease
  - Arthroscopic approach is less invasive, less morbid, and access to sacciform recess
  - Open approach requires radial head excision for exposure
- Arthroscopic debridement and capsular release
  - Moderate to severe disease with limited involvement of ulnohumeral joint, symptoms at extremes of motion
  - Advantages: less morbidity than open
  - Relatively contraindicated in the setting of previous ulnar nerve transposition due to the increased risk of iatrogenic nerve injury
- Open debridement and capsular release
  - 3 different techniques: Outerbridge–Kashiwagi procedure, medial over the top approach, or lateral column approach
  - Better than arthroscopic debridement in patients with more advanced disease, or for surgeons with limited elbow arthroscopic experience
- Ulnohumeral distraction interposition arthroplasty

  - Young active patient (<65 yrs of age) with end-stage primary degenerative or posttraumatic arthritis with a painful arc of motion
  - Patients who meet the indications for a total elbow arthroplasty but are unwilling to follow the activity restrictions involving no lifting >10–15 lb or repetitive lifting >2 lb
  - Rarely indicated
- Radial head resection, partial interpositional arthroplasty, partial joint arthroplasty, radiocapitellar hemiarthroplasty, distal humerus hemiarthroplasty
  - Young, active patients with isolated posttraumatic arthritis isolated to radiocapitellar articulation or distal humerus articular surface
- Total elbow arthroplasty
  - Severe RA disease states (Mayo grade III–V)
  - Primary degenerative or posttraumatic arthritis in low demand patients >65 years of age with a painful arc of motion who have failed all other treatment options.
  - Must be willing to live with activity restrictions of no lifting >10–15 lb or repetitive lifting >2 lb
- Elbow arthrodesis
  - Young active patient with unilateral posttraumatic arthritis who requires a strong stable joint.
  - Rarely indicated.
- Ulnar nerve decompression (can be added in addition to above procedures)
  - Preoperative loss of flexion <100 degrees
  - Preoperative loss of extension >30 degrees
  - Symptoms of ulnar nerve irritation

Surgical Techniques

- Arthroscopic debridement and capsular release

- After general anesthesia is administered, the patient may be positioned either supine, prone, or lateral decubitus depending on the preference of the surgeon.
- For lateral decubitus, a beanbag can be utilized with a padded arm holder to hold the operative arm with the elbow flexed at 90 degrees.
  - A nonsterile tourniquet is applied as high up in the brachium as possible. The elbow is placed in 90° of flexion.
    - The arm is then prepped and draped in the standard fashion.
    - Gravity inflow is preferred due to the risk of compartment syndrome.
    - Using a marking pen, the ulnar nerve and bony landmarks should be marked.
    - Insufflate the elbow joint with ~25 cc of sterile saline through the lateral soft spot, which is bounded by the radial head, lateral epicondyle, and olecranon.
    - The arthroscope is typically inserted through the anteromedial portal, which is 2 cm distal and 2 cm anterior to medial epicondyle (danger is medial antebrachial cutaneous nerve).
    - This portal allows visualization of capitellum, radial head, and anterior surface of humerus.
  - Next, a midanterolateral portal (3 cm distal and 1 cm anterior to lateral epicondyle) is created for instrument insertion under direct visualization with the scope directed radially using a spinal needle.
    - Once this portal is placed, switch the camera to this portal allowing visualization of the coronoid process and olecranon.
    - Loose bodies, osteophytic spurs, and, in the case of RA, synovium can be débrided and excised.
  - For debridement of the poster compartment of the elbow, the posterolateral portal can first be created 2–3 cm proximal to tip of olecranon and just lateral to edge of triceps tendon.
  - Finally, the direct posterior portal can be made ~3 cm proximal to tip of olecranon in midline of triceps tendon.

    - These portals allow debridement of olecranon process, olecranon fossa, and posterior capitellum.
- Outerbridge–Kashiwagi procedure
  - The Outerbridge–Kashiwagi procedure was originally described as an open procedure, but can be performed either open or arthroscopically.
  - Opponents of this procedure will note its limited ability for a sufficient anterior release and anterior osteophyte debridement.
  - A midline straight posterior incision ~10 cm in length is made over the arm from proximal to the tip of the olecranon.
  - The triceps muscle is split in line with its fibers allowing access to the olecranon fossa.
  - Using a chisel (or burr), a fenestration ~1.5 cm in diameter is made in the olecranon fossa allowing debridement of the anterior elbow compartment.
  - Once debridement is complete, the split in the triceps should be repaired.
- Total elbow arthroplasty
  - Implant options for total elbow arthroplasty include either a nonconstrained or semiconstrained device.
  - *Unconstrained* prostheses are typically indicated in younger patients with stable articulation.
  - *Constrained* prostheses are used for ligamentously unstable patients, RA patients, or in the setting of inability to adequately perform soft tissue balancing.
    - Constrained prosthesis is more commonly used, and the surgical technique is described below.
    - The patient should be positioned supine with a sandbag or bump underneath the ipsilateral scapula.
    - A tourniquet should be placed as proximal as possible on the operative extremity.
    - The ipsilateral upper extremity should be prepped and draped in the standard fashion.

- Options for approach include triceps sparing, triceps splitting, and triceps reflecting (Byran–Morrey approach).
  - Using the Byran–Morrey approach, a straight incision is made posterior on the elbow between the tip of the olecranon and lateral epicondyle.
  - The *ulnar nerve* should be identified and mobilized at the medial border of the triceps for subcutaneous transposition.
  - The medial border of the *triceps,* along with *anconeus,* should be put under tension and incised subperiosteally from their insertion.
  - The *lateral ulnar collateral ligament complex* is then released from the humerus followed by the medial collateral ligament.
  - Utilizing a saw or osteotome, the tip of the *olecranon* can be removed from the ulna with the triceps attached allowing for exposure of the articular surfaces of the elbow.
    - Once adequate exposure is achieved, humeral preparation can begin by removing the center of the trochlea.
    - A high-speed burr can be used to enter the olecranon fossa, and at this point, if the patient has a loss of extension, the surgeon can consider shortening the humerus by 1 cm or less with little risk to affecting the biomechanical function of the triceps.
    - An intramedullary rod with cutting jig is then placed down the canal, and the humeral cuts are made.
  - The *humeral canal* is then widened in a progressive fashion to accept the trial component.
  - The *ulnar canal* can be found with a high-speed burr followed by a handheld reamer and then should be prepared to the appropriate size.
  - Next, the trial components should be inserted and put through a range of motion.
    - If unsatisfactory, appropriate adjustments should be made.
    - If satisfactory, the actual components can be cemented in place and can be secured in place with interlocking cross

pins.

- The range of motion should again be confirmed, and next, the triceps/olecranon fragment can be reattached using heavy nonabsorbable suture.
- The ulnar nerve should be protected throughout closure, and the arm should be placed in an extension splint postoperatively.

Complications

- Arthroscopy
  - Nerve injury—most common is neurapraxia of ulnar nerve (avoid posteromedial portal)
  - Compartment syndrome—minimized by avoiding pump inflow
  - Septic joint
  - Portal fistulas
  - Hemarthrosis
  - Heterotopic ossification—less than with open debridement
- Outerbridge–Kashiwagi procedure
  - Inadequate debridement
  - Infection
  - Wound healing
  - Iatrogenic fracture
- Total elbow arthroplasty
  - Infection
  - Wound healing
  - Instability
  - Nerve injury, especially ulnar nerve
  - Triceps insufficiency
  - Implant failure

- Periprosthetic fracture
- Implant loosening secondary to polyethylene wear or patient noncompliance to lifting restrictions

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BIOMATERIALS AND BIOMECHANICS IN TOTAL HIP ARTHROPLASTY

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METALLURGY

Metallurgy in orthopedic implants including total hip arthroplasty (THA) components involves most commonly three types of alloys: steel (iron based), titanium based, and cobalt based. For optimal performance in physiologic environments, they must have suitable mechanical strength, biocompatible and biologic stability structurally. The most important material mechanics to understand are elastic modulus, yield stress, ultimate tensile stress, and fatigue stress.

The Three Most Common Alloy Implants

- **316 L (L = low carbon: greater corrosion resistance) STAINLESS STEEL** contains iron-carbon as the majority base, chromium, nickel, molybdenum, and manganese.
  - Chromium allows passive surface oxidation to resist corrosion.
  - Nickel resists corrosion and stabilizes the molecular structure.
  - Molybdenum hardens the oxide layer and prevents pitting and crevice corrosion.
  - Manganese stabilizes the molecular structure.
  - Stainless steel is biotolerant (thin fibrous layer forms as direct leaching of chemicals irritate surrounding tissue) and is susceptible to corrosion. It is not used for THA implants but mostly for plates and screws.

- **TITANIUM ALLOYS (Ti-6 Al-4 V)** are extremely biocompatible, bioinert, light weight, and rapidly form passive oxide coat to resist corrosion.
  - They generate less wear when highly polished.
  - They have a low modulus of elasticity (half that of cobalt and stainless steel alloys) and high yield strength and are closest to the axial and torsional stiffness of bone (less stress shielding).
  - They are used mostly for femoral stems.
  - Titanium is not used in articulating components because of poor shear strength, wear resistance, and increased notch sensitivity.
- **COBALT ALLOYS ([Co-Cr-Mo] 65% Cobalt, 35% Chromium, 5% Molybdenum, sometimes contains nickel to aid in forging process)** are much stiffer materials (increased ability to stress shield) better able to resist wear and corrosion.
  - They have high fatigue resistance and high ultimate tensile strength.
  - These alloys are therefore used mostly for load bearing and articulating surfaces in THA like femoral heads.
  - Cobalt alloy is bioinert.
- **TANTALUM** is a transitional highly porous metal usually deposited on pyrolytic carbon backbones (created by heating and depositing hydrocarbons on graphite substrate).
  - It is highly corrosion resistant, highly inert, as well as highly resistant to wear and mechanical fatigue.
  - It has a low modulus of elasticity similar to cortical bone.
  - Tantalum is used in acetabular/femoral stem coatings to allow for better bone ingrowth (osteoconductive).
- **CORROSION** is a chemical reaction that weakens the metal.
  - There are three main types: fatigue, galvanic, crevice.
  - Corrosion severity depends on chemical composition of metal (stainless steel > cobalt and titanium).
    - ***Fatigue corrosion*** occurs when the passive film layer is disrupted by micromotion and scratching between modular components

(**FRETTING**).

- ***Galvanic corrosion*** usually occurs when electric current exists between two different metals (i.e, titanium stem and cobalt chrome femoral head). Mixed components will all have some degree of galvanic corrosion; however, to avoid catastrophic galvanic corrosion never mix stainless steels with cobalt chrome or titanium.
- ***Crevice corrosion*** happens in a structural defect in metal and occurs when fluid in contact with a metal becomes stagnant, resulting in a decrease in oxygen and pH and speeding up destructive process and increases depth of defect and becomes self-propagating (Fig. 4.1).

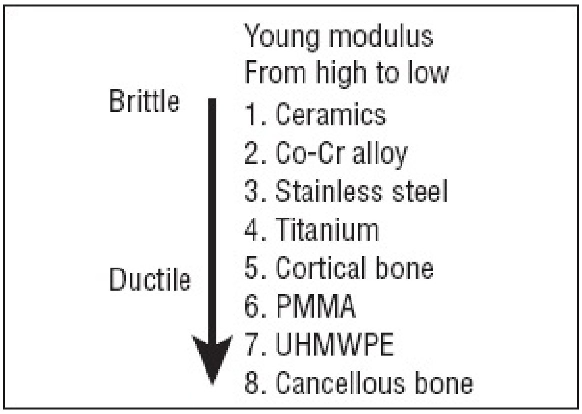

Figure 4.1 Young modulus.

Other Materials Used in TJA

- **UHMWPE (ultra-high molecular weight polyethylene)** has a low coefficient of friction, ideal for articulating bearing surface.
  - Several factors affect polyethylene wear: material quality, degree of cross-linking, strength, toughness, thickness, sterilization technique, storage, and shelf life.
  - A polyethylene wear rate <0.1 mm/yr is at low risk of developing osteolysis.
    1. High crystallinity (optimal is 45–65%) make it less resistant to crack initiation and propagation.
    2. UHMWPE is machined from ram-extruded bar stock or direct compression heat-molded from powder.
    3. Increased thickness is better because less stress (minimal

thickness in acetabular liners usually 6 mm)

4. Biomechanical properties affected by

   a. gamma irradiation for sterilization/cross linking (25–40 K Gy, or 5–10 mrad) increases cross-linking and makes it more crystalline; thus better wear characteristics but also formation of free radicals.

   b. annealing (heat below melting point) prevents loss of crystalline structure and removes some oxidative free radicals. Remelting removes all free radicals but makes material more amorphous and decreases fracture toughness.

   c. storage/sterilization in inert atmospheric medium (argon/plasma gas) decreases reintroduction of free radicals —NEVER STERILIZED IN AIR.

   d. vitamin E doping or other antioxidants added to polyethylene to quench free radicals.

- **CERAMICS** can be used as acetabular liners or in femoral head components.
  - They have low coefficient of friction, have high resistance to wear, are strong in compression, have high modulus of elasticity, are brittle (low yield strain), and are susceptible to cracking with sharp edges.
  - Strength is improved with increased density, increased crystallinity, and decreased porosity.
  - The hardness, wettability, inertness, and biocompatibility make them ideal for bearing surfaces.
  - Because of high Young modulus compared to bone, ceramics are never in direct contact with bone due to high incidence of loosening (Fig. 4.1).
  - With malpositioning of components, edge loading and femoral neck impingement can cause crack propagation and catastrophic failure.
  - Ceramics include aluminum oxide and zirconium oxide.
    - **Aluminum oxide (AL^2O^3)** is highly biocompatible with high frictional resistance, low fracture toughness, and tensile

strength.

      - Fracture can result from microstructural flaws such as large grain size and impurities.
    - **Zirconium oxide (Zirconia)** is also used as stabilizing structure to prevent crack propagation when mixed with aluminum oxide.
      - It can be maintained in a **metastable tetragonal** crystal structure with fine grain structure with the addition of stabilizing oxide (yttrium oxide [Y^2O^3]).
      - It can be used as an extremely thin (0.004 mm) but extremely adherent bearing surface from nitrogen ion implantation technique on metal bearings that significantly increases surface microhardness thus making surfaces highly wear resistant.
      - Compared to aluminum oxide, zirconium oxide has increased fracture toughness, bending strength, and decreased elastic modulus.
- **PMMA (polymethylmethacrylate)** is acrylic cement used as a grouting agent to provide immediate fixation of total joint components to bone.
  - The tensile strength is similar to cancellous bone and allows gradual transfer of load from implant to bone.
  - It reaches its ultimate strength in 24 hrs.
  - It is strongest in compression and weakest in tension.
  - Poor fatigue strength is related to its porosity.
    - Therefore ways to decrease porosity and decrease cracking include third-generation cementing techniques like vacuum mixing, retrograde filling, and pressurization before implant insertion.
  - PMMA can cause local tissue necrosis secondary to its exothermic reaction, it can reach temperatures of 100 degrees Celsius, and leaching of monomer can cause hypotension.
  - Heat-stable antibiotics can be added without significant decrease in fatigue strength.

- **HYDROXYAPATITE ($Ca_{10}(PO_4)_6(OH)_2$)** resembles natural mineral in vertebrate bone and is a bioactive material used as a coating on some THA components to augment bone implant fixation.
  - It is stronger in compression than tension but has low resistance to fatigue failure.
  - It can be plasma sprayed on roughened implants (~20–50 μm thick) to act as an osteoconductive surface.
  - It allows for more rapid closure of gaps between bone and prosthesis.

Femoral Stem Fixation: Biomaterial and Biomechanical Concepts

- **Cemented femoral stems** allow microinterlock with endosteal bone. Cement will fatigue with cyclic loading; therefore, it is imperative to maintain a sufficient even mantle around the implant (not <2 mm)
  - Mantle defect is an area where the prosthesis touches the bone = area of high stress.
  - Better in low demand older patient with porous bone
  - Cement success increased by cement porosity reduction (vacuum mixing), canal pressurization of cement, pulse lavage of bone, stem centralization, and use of stiffer stem.
  - Also place stem in neutral or slight valgus to reduce stress on medial cement mantle.
- **Cementless femoral stems** rely on two methods of biologic fixation: bone ingrowth and bone ongrowth
  - *Bone ingrowth:* pores in metal alloy allow bone ingrowth. **Optimal pore size (50–1 50μm)**
  - *Bone ongrowth:* stability achieved when bone grows onto imperfections of rough grit-blasted titanium surface. Amount of on growth depends on surface roughness.
  - Grit-blasted stems achieve initial rigid fixation with press fit technique of gradual tapered stems to allow for compression hoop

stresses. Component is slightly oversized in regards to bone preparation. In acetabular shells press fit allows for hoop stresses at the rim of the acetabulum.

- Line-to-line technique is when bone contour is prepared, so it is the same size as the implant, which is utilized in fully porous coated implants, which allows for initial stability by frictional fit (scratch fit).

- **Femoral stem loading**
  - **Proximal porous coating** mechanical load is transferred to metaphysis and proximal diaphysis thereby maintaining proximal bone density
  - Extensive porous coating and well-fixed cemented stem transmits load through well-adhered endosteum and is loaded distally, consolidation of bone will be seen near end of femoral stem called **spot weld**.
    - Because the load is bypassing the proximal bone, proximal **stress shielding** can occur and it implies a well-fixed distal loading implant as a result of modulus mismatch between femoral stem and femoral cortical bone.
    - This is especially seen in more rigid and stiff implants (i.e., large solid cylindrical cobalt chrome stem with porous coating).
  - Cylindrical stem diameter effects stiffness: proportional to R^4
  - Stem breakage (cantilever bending) can result from thinner diameter stems fixed well distally but loose at the top as a result of cyclic loading and fatigue failure of the stem in the middle.
- **"Rule of 50s"** to determine if porous-coated stem component can provide solid fixation.
  - Optimal pore size (50–150 µm), porosity (50%), gap between prosthesis and bone (50 µm), micromotion (50–100 µm) → anything >150 µm will lead to fibrous ingrowth.

Articular Bearing Options in THA: Biomaterial and Biomechanical Concepts

Tribology is the understanding of science of friction, lubrication, and wear with interacting surfaces.

- More traditional bearing options: **Hard on soft** (metal on poly, ceramic on poly)
  - 3 types of PE wear
    - adhesive (submicron particles being delaminated and squeezed together between bearing surfaces)
    - abrasive (rough spots scratching the PE)
    - third body (from debris).
  - Hard on PE liner prone to **ADHESIVE WEAR**, larger heads yield more volumetric wear.
- Alternative bearings: **hard on hard** (metal on metal, ceramic on ceramic, metal on ceramic).
- **Asperities** are carbide microscopic-elevated rough spots on bearing surfaces, which always make contact with each other → increase wear.
  - Pits in ceramic bearings increase surface roughness and wear.
- **Lubrication** with boundary lubrication (synovial fluid will separate two surfaces enough to prevent wear → occurs when hip at rest or in slow motion.
  - Hydrodynamic (fluid film) lubrication while walking, asperities are separated enough to not touch, this type of lubrication requires increased angular velocity of femoral head.
  - Normal human joints have coefficient of friction of .002–0.04, THA (metal on PE = 0.05–0.15). Hydrodynamic lubrication is affected by
    - **radial clearance:** Radius of cup minus radius of head, optimal provides equatorial contact with high conformity, too small → no fluid ingress and components will seize (lock), too large → of a difference then contact point too small (in the polar region) = increased wear.
    - **ra (surface roughness):** ultrasmooth surface allows better fluid film layer

- **Bearing size:** bigger surface allows better fluid film mechanics.
- **Sphericity:** any irregularity of perfect sphere will generate high stress points.
- **Bearing material:** Smooth finishes with Co-Cr and ceramics = better wear.

- Zirconia and titanium heads on poly perform poorly secondary to surface roughness → ABRASIVE WEAR.
- Metal smearing on ceramic head is from transfer of metal shell on ceramic head secondary to subluxation and edge loading → "**stripe wear"** when ceramic on ceramic, increased surface roughness in this region.
- **METAL ON METAL:** Very small but more numerous quantity of particles generated (0.015–0.12 μm) when compared to PE (0.5–5 μm), very low linear wear and volumetric wear compared to PE.
  - Undergo "run in wear" where rough spots (asperities) from manufacturing process are polished out in vivo, in first 1 million cycles then reaches steady state wear.
  - Particles generated can dissolve into cobalt and chromium ions detectable in blood and urine.
  - T-cell lymphocyte is biologic response from metal debris (Co-Cr)
    - Soon after implantation = hypersensitivity reaction usually to Ni
    - 3–5 yrs later = particulate induced T-cell response (**PITR**) → involves highly activated RANKL system → pseudotumor formation (Co and Cr ions combine with serum protein, which is recognized by T-cell) → stimulates cytokines IL-2, IL-6, INFγ → detectable sometimes massive effusion on MRI or ultrasound, osteolysis around implants, and tissues show inflammatory mass primarily of lymphocytes (**ALVAL**—aseptic lymphocytic and vasculitic-associated lesion).
  - Do not use metal on metal in woman of childbearing age (ions cross placenta).
  - Do not use metal on metal in renal failure patients (cannot excrete ions)
  - Local tissues can be predisposed to local metaplasia/dysplasia but

no long-term cancer risk proven.
  - Have fallen out of favor.
- **CERAMIC ON CERAMIC**
  - **Advantages:** lowest wear, thus fewer particles generated (size 5–90 nm), no ions and bioinert.
  - **Disadvantages:** limit on head sizes and length, manufacturing constraints on thickness of insert.
  - **Hip squeak:** psychologically disturbing to patients, stripe wear/edge loading.
  - If ceramic on ceramic fails then must revise to another ceramic on ceramic because microshards will remain and cause rapid PE wear.
  - If changing femoral head in revision on used stem trunnion with ceramic head must use metal jacket to prevent roughened trunnion from causing burst fracture on ceramic head with loading.

Osteolysis in THA

- In THA *wear* occurs from femoral head on PE-bearing surface (adhesive wear) and from micromotion of PE liner on acetabular shell (backside wear) → generates submicron particles, which can elicit osteolytic response.
- Macrophages become *activated* after uptake of submicron PE particles → activates additional cytokines (TNF-α, IL-1, TNF-β, IL-6, PDGF-**receptor activator of nuclear factor B ligand [RANKL]**).
  - RANKL made by osteoblast and attaches to RANK receptor on osteoclast → stimulates bone resorption.
  - **Osteoprotegerin (competitive inhibitor) will bind and block RANKL from activating osteoclast.**
- In THA the *buildup of inflammation* to PE particles increases intra-articular hydrostatic pressure.
  - This results in dissemination of PE particles throughout **effective joint space.**

- Linear wear (distance head penetrates into the cup) → rates that exceed 0.1 mm/yr are associated with osteolysis.
  - Small heads will have relatively more linear wear (failure from PE cup penetration) than volumetric wear, and larger heads show the opposite (failure more from osteolysis).
- X-rays show endosteal scalloping in femoral canal and round lytic lesions behind cup especially around screws.

Biomechanics after THA

Prevent chance of dislocation by considering component design, alignment, and soft tissue function and tension.

- Component design
  - **Primary arc range** = functional range of motion of bearing components before impingement.
  - **Controlled by head/neck ratio:** increased primary arc and decreased risk of impingement by maximizing ratio.
  - Examples that decrease head/neck ratio: neck skirt, acetabular hoods/lipped liners, or constrained liners, whereas larger heads and tapered necks or thinner liners increase the ratio.
  - **Lever range** is **controlled by head radius** → larger head has more excursion distance before impinging on cup and risk levering out.
- Component alignment
  - Goal is to center primary arc within patient's functional hip range of motion. Malalignment will generate a stable and unstable side to functional hip range, either retroversion/excess anteversion.
    - **Angles:** cup anteversion 20°, coronal tilt angle 35–50°, stem anteversion 10–15°
    - Excess anteversion of cup and or stem-risk anterior dislocation, retroversion-risk posterior dislocation
    - High coronal tilt angle = vertical cup-risk posterior-superior dislocation and increased wear
    - Low coronal tilt angle = horizontal cup-risk impingement

- Soft tissue tension and function
  - Most important is abductor complex (gluteus medius and minimus) and must restore and maintain proper hip abductor tension to remain stable.
  - This is done by restoring the following: normal hip center of rotation, femoral neck length, and head offset.
  - Added benefit is decreased joint reaction force (JRF).
  - Problems if hip mechanics not restored: **offset decreased** → weak abductor tension, increased JRF.
    - This will result in Trendelenburg gait/lurch, increased risk for dislocation.
    - Can also be caused by using short neck or low neck cut → can result in greater troch impingement against pelvis.
  - Using high offset stem/neck can restore abductor tension and lever arm thus decreasing JRF without increasing leg length, however, if too much can cause troch bursitis/chronic lateral hip pain.
  - Increasing head or neck length to restore tension can be done but can risk lengthening the leg.
- **Changes to decrease JRF:** in other words shift center of rotation medial
  1. Move acetabular component medial/anterior/inferior
  2. Increasing femoral component offset
  3. Shifting body weight over hip, cane in contralateral hand, or carrying load in ipsilateral hand.
  4. Others: lateralization of greater troch (increase abd tension and lever arm) or long neck prosthesis.

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HIP PAIN, ARTHRITIS, AND OSTEONECROSIS

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Hip Anatomy and Pathoanatomy

The *hip joint* (femoroacetabular joint) is a diarthrodial or ball and socket joint. The *acetabulum* is formed by the fusion of three bones: ilium, pubis, and ischium. There are three main *ligaments* or thickenings of the hip capsule that provide stability to the hip joint: the iliofemoral (Y ligament of Bigelow), ischiofemoral, and the pubofemoral.

The *blood supply* to the femoral head comes primarily from the medial circumflex femoral artery that forms the extracapsular arterial ring with the lateral circumflex femoral artery. Ascending cervical branches from this ring go on to form the retinacular arteries that will form the epiphyseal arterial supply consisting of the lateral and inferior epiphyseal branches. These epiphyseal vessels provide the terminal blood supply to the epiphysis and must be protected during hip preservation type procedures.

Pathology

- While the most common cause of primary osteoarthritis (OA) is idiopathic, there is evidence to support that femoroacetabular impingement (FAI) and acetabular dysplasia are responsible for the majority of those cases.
- Other common causes of secondary OA include developmental dysplasia, trauma, slipped capital femoral epiphysis, Legg–Calvé–Perthes disease, childhood disorders, neuropathic arthropathy, and

infection.

- In osteonecrosis or avascular necrosis (AVN) of the femoral head, there is an interruption to the blood supply of the femoral head. This leads to an inability for the bone to remodel and ultimately to fatigue failure of the femoral head. Once the femoral head is aspherical, the acetabular cartilage will also become compromised.

History and Presentation

- Patients report gradually progressive pain in their groin region that may be cyclical, constant, or activity related in nature.
- Pain is most commonly localized to the groin but also may be localized to the thigh, buttock, or lateral hip.
- Activities such as walking, coming from a sitting position to a standing position, maneuvering stairs, and pivoting may worsen pain.
- Patients may also complain of restriction in range of motion (ROM) with changes in sitting posture, difficulty tying shoelaces, or climbing stairs.

Differential Diagnosis

Extra-Articular

- Medial snapping hip syndrome
  - Patients report minimal pain and a popping sensation over their groin when the iliopsoas tendon catches on the lesser trochanter, iliopectineal ridge, or anterior-inferior iliac spine.
  - This happens when the hip goes from a flexed, abducted, externally rotated to an extended, neutral position.
- Lateral snapping hip syndrome
  - Patients typically report pain over the lateral aspect of the hip and a popping sensation when the iliotibial band, particularly the thickened posterior aspect, or the anterior aspect of the gluteus maximus slides over the greater trochanter.

- Sports hernia or athletic pubalgia
  - Chronic groin pain radiating down the adductors.
  - Frequently seen in athletes.
  - Associated with a dilated superficial inguinal ring of the inguinal canal.
  - Tears seen in the external oblique aponeurosis, conjoint tendon, fascia transversalis, and internal oblique muscle from the pubic tubercle.
  - Pain is reproduced with things that cause an increase in intra-abdominal pressure including coughing and sneezing.
- Low back pain
  - Typically the pain is in the posterior buttock region and can radiate down past the knee if a spinal nerve (L3 or lower) is involved.
  - Hip flexion/rotation should not aggravate the patients' "hip" pain.

Intra-Articular

- OA—see above
- Inflammatory arthritis
  - Rheumatoid arthritis, spondylarthrosis, psoriatic arthritis, SLE, etc.
  - There are typically other constitutional symptoms to help with this diagnosis.
- FAI
  - Usually pain with prolonged sitting or coming from sitting to standing position
- Developmental dysplasia of hip, SCFE, LCP, childhood disorders
  - History of childhood disorders and complaints of hip instability or pain similar to FAI
- Labral tear
  - Pain with flexion such as sitting for prolonged periods or with pivoting, may be associated with mechanical symptoms of catching, clicking, or locking
- Synovial chondromatosis

  - Cartilaginous bodies in the synovial tissue
- Septic arthritis
  - Fairly rapid onset secondary to bacterial proliferation in the joint
- Osteonecrosis
  - See above. Among other causes most commonly associated with a history of high-dose or prolonged steroid use in the past or a history of alcoholism

Physical Exam

- Assess gait, Trendelenburg test, and leg lengths.
- Assess hip ROM in flexion, extension, abduction, adduction, internal rotation, and external rotation.
  - Patients will have limited ROM, particularly with hip flexion and internal rotation.
  - Check for hip abductor strength in lateral decubitus position.
    - *Positive Stinchfield test*—pain with resisted hip flexion with knee extension.
    - *Anterior impingement test*—groin pain with hip flexion, internal rotation, and adduction.
    - *Patrick test* (FABER) with hip flexion, abduction, external rotation, and knee flexion may result in groin pain (hip etiology) or gluteal pain (SI Joint).
    - *Straight leg raise test*—radicular pain in leg with contralateral straight leg raise is highly suggestive of lumbar origin.

Imaging

- Radiographs
  - OA
    - Eccentric joint space narrowing, particularly the superior aspect of the femoroacetabular joint.

        - Osteophytes from lateral acetabular rim, medial osteophytes at acetabulum, superolateral aspect of femoral neck, inferomedial femoral neck.
        - Subchondral cysts in superolateral aspect of acetabulum due to trapped joint fluid from tears in the articular cartilage.
    - Inflammatory arthritis–like RA
        - Concentric joint space narrowing with minimal osteophytes.
        - Osteonecrosis may demonstrate lucency with sclerotic border at anterosuperolateral femoral head associated with subchondral collapse and a crescent sign.
- MRI
    - Usually unnecessary in the setting of OA or inflammatory arthritis.
    - Subchondral cysts have increased signal on T2-weighted MRI in acetabulum.
    - The articular cartilage will have intermediate signal intensity on T1-weighted and T2-weighted MRI; therefore, thinning of the articular cartilage can be appreciated with the higher strength MRI machines.
    - The labrum will have decreased signal on both the T1 and T2 and an increased signal intensity in the labrum suggests a tear, easier to appreciate with gadolinium contrast injected into the hip joint.
    - Areas of osteonecrosis may demonstrate increased signal on T2-weighted MRI and intermediate signal on T1- and T2-weighted MRI depending on stage of osteonecrosis.

Nonoperative Management

- NSAIDs, weight loss, activity modification, abductor strengthening, and physical therapy for modalities and hip strengthening.
- Intra-articular cortisone injections under fluoroscopy can be helpful in the mild to moderate stages of OA.

Operative Indications

Hip Osteoarthritis

- Patients with clearly defined hip arthritis and hip pain refractory to conservative management that significantly limits patients' occupational, recreational, or daily living activities are candidates for a total hip arthroplasty (THA) or resurfacing arthroplasty (SRA).
- The indications for SRA are very strict, however, generally a highly active male with large femoral heads and OA without significant proximal femoral or acetabular deformities and without metal allergies are excellent candidates for SRA.

Contraindications

- Both THA and SRA are contraindicated in the setting of active hip infection or bacterial nidus elsewhere in the body (abscess, boil, endocarditis), significant medical comorbidities unsuitable for surgery, or nonambulatory status.
- There are numerous contraindications for SRA including small femoral head, coxa breva, poor bone mineral density, femoral head cysts greater than 1 cm, acetabular dysplasia or deficiencies, uncontained osteonecrosis lesions, inflammatory arthritis, proximal femoral version deformities, and metal allergies.

Osteonecrosis

- Treatment depends on the severity of the disease process in the affected hip using the Ficat classification.

1. Stage 0
    a. Clinical symptoms: mild to nil
    b. Radiographs: normal
    c. MRI: mild edema (increased signal on T2-weighted images)
2. Stage 1
    a. Clinical symptoms: moderate groin pain
    b. Radiographs: normal, possibly osteopenia
    c. MRI: moderate edema
    d. Bone scan: increased uptake in hip region
3. Stage 2

a. Clinical symptoms: moderate groin pain, some limitation in movement

b. Radiographs: sclerosis with osteopenia

c. MRI: defect with identifiable borders, decreased signal on T1

d. Bone scan: increased uptake in hip region

4. Stage 3

a. Clinical symptoms: moderate to advanced groin pain with limitation in movement

b. Radiographs: cortical collapse with crescent sign

c. MRI: defect with identifiable borders and cortical collapse, decreased signal on T1-weighted images

d. Bone scan: not needed past this stage

5. Stage 4

a. Clinical symptoms: significant groin pain with loss of motion and pain radiating down the thigh

b. Radiographs: cortical collapse with signs of OA

c. MRI: cortical collapse with findings of OA

- Ficat stages 0, 1, 2 can be treated with bisphosphonates as well as drilling into the femoral head to increase vascularity or a free fibula autograft for the precollapse stages of osteonecrosis. Once the condition progresses to collapse and/or joint involvement (Ficat stages 3, 4), THA is the most reliable option.

Surgical Technique

- **Pre-op area:** Take a history and repeat physical exam in pre-op. Be aware of anesthesia plan, antibiotics. Obtain consent and mark operative site. Always consent patients undergoing SRA for THA also.
- **Approach for total hip arthroplasty**
  - **Anterior**
    - Patient supine on table with ability to use fluoroscopy to

visualize the pelvis.

- Interval is between the tensor fascia lata (TFL) and the sartorius.
- Rectus tendon is then identified and released.
- Anterior capsulotomy with H or Z pattern performed to visualize hip joint.
  - Femoral neck osteotomy per preoperative plan performed to gain access to the acetabulum.
  - Retractor placement and the delivery and visualization of the femoral canal is especially critical for this approach.

- **Anterolateral**
  - Lateral positioning with axillary roll and posts or positioners used to hold pelvis in stable position.
  - Interval is between TFL and gluteus medius.
  - Typically, the anterior ⅓ of the gluteus medius is taken down to allow greater mobility of the femur and increase visualization of the acetabulum.
  - Externally rotate and extend the hip to facilitate dislocation.
  - After the hip is dislocated, proceed to a femoral neck osteotomy as determined by preoperative planning.
- **Posterior Approach**
  - Posterior-lateral positioning with axillary roll and posts or positioners used to hold pelvis in stable position.
  - An incision is made over the tip of the greater trochanter extending toward a point between the superior most portion of the iliac crest and the posterior-superior iliac spine.
  - After splitting the muscle fibers of the gluteus maximus and incising the iliotibial band, take down the piriformis and the short external rotators.
  - Then a posterior capsulotomy is performed followed by femoral neck osteotomy per preoperative plan.

- All approaches
  - Remove labrum and soft tissue in acetabular fossa.

- Must visualize acetabulum completely in depth and circumference. May release transverse acetabular ligament if needed.
- Prepare acetabulum with successively larger reamers, being careful to medialize with breaching the medial wall and directing the reamer to not ream away the posterior wall.
- Use a trial cup to ensure that there has been concentric reaming with adequate coverage to be able to securely hold an acetabular shell.
- Be very mindful of pelvis positioning and appropriate acetabular inclination (40 degrees) and anteversion (10–20 degrees).
- After placing the actual acetabular shell, one or 2 acetabular screws should be placed and directed posterosuperiorly in ilium to ensure stability for bone ingrowth.
- Then place liner.

- Confirm femoral neck cut (based on preoperative planning), then remove the soft tissue sitting in the piriformis fossa (the remnants of the short external rotators).
  - Using a box osteotome, enter the femoral canal with the osteotome starting right next to the greater trochanter to prevent varus position. Follow this with a canal reamer and broach or ream and broach depending on femoral implant.
  - Based on surgical feel, appropriate femoral version, axial stability, and rotational stability, successively perform these steps until to the appropriate-sized stem is reached.
  - When placing the femoral trial with the head and neck, it is extremely important to check stability and leg length.
    - Once this is done, place the actual femoral component and close the capsule and short external rotators with or without femoral drill holes.
    - Please see references for cemented femoral stem technique.

Postoperative Rehabilitation and Expectations

- **Weight bearing as tolerated** immediately postoperatively.
  - Posterior hip precautions with posterior approach per surgeon discretion.
  - Anterior hip precautions for anterior approach per surgeon discretion.
- **Physical therapy**
- **Deep vein thrombosis (DVT) prophylaxis**

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REVISION TOTAL HIP ARTHROPLASTY

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Pathology/Prosthetic Failure

The indications for revision total hip arthroplasty (THA) are defined and can be performed for pain for functional failure. The causes of this pain or functional failure include loosening of the cemented components (bone–cement debonding, implant–cement debonding), loosening of uncemented components, implant wear and osteolysis (from excessive wear debris), periprosthetic fracture, instability, and infection. Lack of bone ingrowth in uncemented hips or lack of cement interdigitation can result in implant loosening. Implant wear leads to wear debris, which subsequently incite an osteoclastic cascade resulting in osteolysis and possible loosening of components. Cognitive deficits (e.g., Down syndrome, alcoholism), neuropathic joints (Charcot arthropathy, spinal muscular atrophy), and hyperflexibility (Marfan syndrome, Ehlers–Danlos syndrome) can predispose patients to repeated hip instability. Infection in the hip joint is typically caused by local factors or bacteremia due to a compromised host immune system, poor hygiene (monitor dental health), bladder infection, endocarditis, etc.

History/Presentation

- A patient will typically present with pain or instability.
- The timing of onset of pain, progression of pain, relation to activity, and constitutional symptoms are important to ascertain.
  - Pain ever since the initial THA may indicate infection or lack of

bone ingrowth.

  - Pain at rest may indicate infection or remote pathology such as spinal pathology.
  - Pain suggestive of a loose acetabular component is typically activity related or present when the patient has start-up groin pain when coming from a seated to standing position.
  - Pain suggestive of a loose femoral component is typically activity related and associated with thigh pain.
  - Thigh pain may also be associated with a disparity with the Young modulus of elasticity between the femur and a solid cobalt chrome cylindrical femoral implant.
  - Persistent pain usually at rest possibly associated with fevers or weight loss is highly suggestive of infection.

Differential Diagnosis

- Trochanteric bursitis
  - Lateral hip pain that should respond to conservative management or steroid injection
- Anterior thigh pain
  - Pain in thigh region that is noted with weather changes and after activity
- Iliopsoas tendinitis/bursitis
  - Groin pain that should be reproducible with flexion/abduction to extension/adduction.
  - An ultrasound/fluoroscopic-guided lidocaine injection can help with this diagnosis.
  - Check radiographs to determine uncoverage of acetabular component anteriorly.
- Infected prosthetic joint
  - Pain with rest and activity
- Aseptic loosening of the components

  - Start-up pain
- Osteolysis
  - Usually no clinical symptoms unless it is accompanied by significant polyethylene wear leading to a leg-length discrepancy or instability.
- Periprosthetic fracture
  - History of trauma and acute pain

Physical Exam

- Observe the patient walk and sit.
- Perform a Trendelenburg test (have patient stand on each leg while checking for any pelvic tilt), assess leg-length discrepancy, or antalgic gait.
- Check the hip range of motion: flexion, abduction, adduction, internal rotation, and external rotation in extension.
- Check for tenderness at greater trochanter and also with resisted hip abduction. Check for pain with resisted hip flexion.
- Check for positive straight leg raise test to rule out spinal pathology.
- Any pain radiating distal to the knee is unlikely to be from the hip.

Imaging

Radiographs

- **AP of the pelvis and hip** are needed to assess leg lengths, offset, eccentric polyethylene wear, osteolysis, heterotopic ossification, loosening or subsidence of components, acetabular migration, fractures, and dislocations.
- Osteolysis and implant loosening or subsidence can be assessed by reviewing serial radiographs.
  - **Cross-table lateral** of the hip to assess cup version and look for lucency around the components.

- **Frog leg lateral** is helpful in looking at the femoral stem.
- **Judet** (iliac oblique, obturator oblique) views of the pelvis are helpful in assessing lucency around the acetabular component.
- **Full-length lower extremity radiographs** are useful in evaluating a leg length discrepancy.

Femoral Implants

- Cemented femoral implant
  - Circumferential radiolucency between the implant–cement interface and the cement–bone interface is suggestive of a loose stem.
  - A fracture of the cement mantle, fracture of the implant, component subsidence, and progressive circumferential osteolysis around the bone–cement interface are all suggestive of a loose component.
- Cementless femoral implants
  - Presence of patches of bony trabeculae contacting the stem from the endosteum (spot welds) are signs of a stable femoral component.
  - Proximal stress shielding or decrease in radiodensity in the proximal femur that is ill-defined is normal, particularly in fully coated stems.
    - A circumferential, linear radiolucency between the component and bone without component subsidence (based on examination of previous radiographs) is suggestive of stable, fibrous ingrowth.
    - A large, nonlinear radiolucency around a femoral implant is suggestive of an unstable stem.
      - Any signs of a bony pedestal—calcification of bone distal to the tip of the stem is suggestive of a loose femoral component.
      - Increased bone density near the lesser trochanter with a collared stem is suggestive of a stem that is pistoning and therefore must be loose.

CT Scan

This is useful in visualizing defects and bony anatomy accurately in 3 dimensions. Thus, it is useful for preoperative planning and confirming the extent of osteolysis.

Nuclear Scan

Technetium scan is useful in looking at increased bone metabolic activity that suggests infection or loosening. A tagged WBC scan is more useful if you are trying to rule out infection.

Laboratory Work-Up

- Tests
  1. CBC (complete blood count) with differential
  2. ESR (erythrocyte sedimentation rate)
  3. CRP (C-reactive protein)
- These labs are useful in determining whether there is an infection.
- CBC with differential is frequently normal while a significantly elevated ESR and CRP should initiate further work-up for infection including aspiration and/or a WBC-tagged nuclear study, only if needed.

Prevention

- Antibiotic prophylaxis before dental work is debated to decrease the likelihood of a prosthetic infection.
- Avoiding high impact activity will likely decrease the bearing surface wear rate.
- Using a cane or walker for patients with underlying balance problems will decrease the likelihood of falls and consequently periprosthetic hip fractures.
- Regular follow-up will catch early polyethylene wear or osteolysis where the problem can typically be addressed without removing the nonmodular components.

Nonoperative Management

- In patients who have an infected prosthetic joint, aseptic loosening of the components, or fracture nonoperative treatment is rarely indicated.
- In an elderly patient with an infected prosthetic joint with significant medical comorbidities, lifelong treatment with suppressive antibiotics is acceptable with help from an infectious disease specialist.
- Patients with a limited life span and a small amount of osteolysis can be monitored with serial radiographs at regular intervals (every 6 mos).
- Individuals with recurrent hip instability who are poor surgical candidates can be treated with a hip abduction brace and routine follow-up.

Operative Indications

- Reasons for revision surgery: loose components, osteolysis, recurrent dislocations, periprosthetic fracture, and infection.
- Occasionally, a monoblock femoral stem should be removed during a revision because the head is damaged.
- Components with poor track records should also be removed if there will not be excessive loss of host bone during extraction.
- In all patients that are selected for revision surgery, one must know the diagnosis and try to ascertain the etiology.

Treatment

- Once you have an appropriate indication for revision, you must then attempt to predict the bone defect that will be present, so the appropriate components, allograft, and/or augments are available.
- In addition, one must make every reasonable effort to identify the implants from the index procedure.

- This is necessary in case one must explant the components and/or change the modular components.
- Furthermore, preoperative templating is necessary to ensure the following:
  1. Appropriate-size components are available for the anticipated bone defect
  2. Minimize surgical time
  3. Identify location of an osteotomy (e.g., extended trochanteric osteotomy [ETO])
  4. Have the appropriate extraction tools

Paprosky Classification of Femoral Defects

- **Type 1**—Some metaphyseal bone loss but proximal bone is supportive.
- **Type 2**—Metaphyseal bone loss is substantial (no or minimal cancellous bone) with intact diaphysis.
- **Type 3A**—Significant metaphyseal and diaphyseal bone loss with presence of at least 5 cm of "scratch fit" at the isthmus.
  - An extensively coated stem or modular revision stem would be appropriate.
- **Type 3B**—Significant metaphyseal and diaphyseal bone loss with less than 5 cm of "scratch fit" at the isthmus.
- **Type 4**—Extensive metaphyseal and diaphyseal bone loss with a wide femoral canal and thin cortices ("stove pipe").

Paprosky Classification System for Acetabular Defects

- **Type** 1—hemispherical, supportive rim with no component migration (superior or medial).
- **Type 2**—nonhemispherical defect with supportive columns and 2 cm superior migration and intact Kohler line.
- **Type 3B**—nonhemispherical defect with >2 cm superior migration and broken Kohler line.

Surgical Technique

Pre-op Area and Approach

- Take a history and repeat physical exam in pre-op.
- Be aware of anesthesia plan, antibiotics.
- Confirm with the circulator that the appropriate extraction tools, allograft bone, and implants are available.
- It is important to try and incorporate a previous skin incision in order to avoid a skin bridge.
- An ETO can facilitate exposure and component removal.
  - The osteotomy should be at least 12 cm from the tip of the greater trochanter, so that there is sufficient bone for reattachment.
  - It should be long enough to reach the distal cylindrical portion of a cementless stem and the distal tip of a cemented stem.
  - Posterior approach readily permits access to the entire femur by extending the incision.
  - Regardless of approach, it is important to use a surgical table that will allow imaging of the entire femur and pelvis.
- Fluoroscopy or portable radiographs can help look for iatrogenic fractures, appreciate bone defects, confirm component size, or locate broken hardware.

Aseptic Loosening

- After figuring out the reason for the loosening, the loose components must be removed and replaced with components that ultimately rest on solid, stable bone with or without the use of metal or allograft bone augments.
- Cemented cups and femoral stems can become loose from bone–cement debonding or component–cement debonding.
- It is critical to remove as much of the cement as possible, so that the new implant can rest on host bone.
- Massive osteolysis can lead to loosening once there is insufficient bone to hold the components in a stable position.

Osteolysis ± Polyethylene Wear

- Stable components should be left alone unless there is a reason to remove them (e.g., poor liner locking mechanism).
- Bone grafting with cancellous allograft or other bone substitutes can be completed by creating a small cortical window or through direct access, but its necessity is debated.
- The femoral head and liner should also be changed due to microscopic or macroscopic damage.

Recurrent Dislocation

- It is important to ascertain whether the instability is due to malpositioning of the femoral component or the acetabular component.
- Cross-table lateral radiographs and CT scans can be helpful.

Periprosthetic Femur Fracture

- The location of the fracture and the stability of the stem are the critical factors here.
- A fracture distal to a stable component should be treated with standard fracture fixation techniques.
- A fracture at the level of a loose stem should be treated with revision of the stem and cables ± cable plate. If the fracture is at the level of the stem, but the stem is stable then one can treat the fracture with a locked plate and cables.
- Fractures at the level of the greater trochanter can be treated nonoperatively (small displacement) or a claw plate.

Acetabular Bone Defects

- **Type** 1—A hemispherical porous-coated cup ± impacted particulate allograft.
- **Type 2**—The defect in this scenario is not hemispherical, so bone graft or metal augments are useful in addressing the bone loss.
  - A large, porous, hemispherical cup with multiple screws (as many as possible) should provide adequate stability.
- **Type 3A**—Treatment options include proximal tibia or distal femur

allograft with a jumbo, porous, hemispherical cup.

- With trabecular metal augments of multiple shapes and sizes, the need for bulk allograft is typically not needed.

- **Type 3B**—Without pelvic discontinuity
  - One must assess the posterior wall.
    - If there is sufficient posterior wall, metal augments can be used to "fill" the defect followed by a jumbo hemispherical cup.
    - If there is a deficient posterior wall, a hemispherical cup alone will not be stable.
      - In this case, an antiprotrusio cage is necessary.
      - The cage is held to the pelvis with multiple screws into the remaining pelvic bone. Once this is done, a liner is cemented into the cage.
  - Another technique uses the cup-cage construct (a jumbo cup is placed into the remaining host bone followed by an antiprotrusio cage to provide stability) with a cemented liner.
    - This allows host bone to grow into the hemispherical cup, which should decrease the mechanical stress on the cage.
- **Type 3B**—With pelvic discontinuity

Posterior plates or an antiprotrusio cage can be used.

Femoral Bone Defects

- **Type** 1—A primary stem can be used.
  - Typically, there is not much cancellous bone left behind, so a cementless stem is a better option than a cemented stem.
- **Type 2**—A proximal fixation stem will usually not provide sufficient stability.
  - A fully coated stem would be a reasonable option.
- **Type 3A**—A fully coated stem would be acceptable if one can achieve 5 cm of scratch fit.
  - If this is not possible, then a modular revision stem is necessary.
- **Type 3B**—A modular revision stem is likely to provide adequate

fixation; however, it is critical to have a proximal femoral replacement available in case there is not enough supportive bone for axial stability.

- The fixation will be all distal and the conically tapered splines will engage the diaphyseal cortex.

- **Type 4**—An allograft prosthetic composite or tumor prosthesis.
  - The extensive bone loss with thin cortices makes it difficult for a modular revision stem to gain stability with endosteal contact alone.

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PERIPROSTHETIC FEMUR FRACTURES AFTER TOTAL HIP ARTHROPLASTY FRACTURES

AUSTIN W. CHEN • RITESH R. SHAH

Introduction

Periprosthetic total hip arthroplasty (THA) fractures are increasing due to the number of increasing THAs being done and advancing age of the population. The incidence is considered to be less than 1% for primary THAs but increases to as high as nearly 8% for revision THAs. Risk factors include female sex, advanced age, rheumatoid arthritis, osteolysis/loosening, specific implant type, cement use, and revision surgery.

Clinical History

- Low-energy mechanisms are the main cause (>75%).
- A chart review may be necessary for date of surgery, indication for original implantation, documented leg lengths, primary surgical approach, implant and bearing surfaces involved, history of infection, and revision surgeries.
- Loosening of the implant, osteolysis, and infection may be the causes of the acute fracture.
- Clues that the prosthesis was loose prior to injury include thigh pain or start-up (getting out of a chair) pain.
- A social history should include handedness, occupation, ambulatory status, and need for assist devices.

Physical Exam

- Patients will present with pain, possible deformity, or shortened extremity.
- A standard orthopedic exam is warranted and should include the skin (open fracture, postsurgical scar, chronic venous stasis/diabetic ulcers), leg lengths, strength, and neurovascular status.

Differential Diagnosis

- A periprosthetic THA dislocation may present in a similar fashion.
- The most common type is a posterior THA dislocation.
- The affected side will usually appear short and rotated compared to the contralateral side on clinical exam.
- Patients may present with little or no trauma, but will have difficulty weight bearing.
- Plain radiographic imaging will confirm the diagnosis.

Imaging

- Standard AP pelvis and AP & lateral x-rays of the affected hip and femur are necessary.
- It is crucial to evaluate all THA components for signs of loosening and the bone stock surrounding them.
- Dedicated AP & lateral x-rays of the ipsilateral knee are also useful for completeness and to evaluate for fracture propagation.
- Advanced imaging including MRI and CT are rarely necessary, but should be modified with metal suppression software if they are needed.
- When available, use prefracture radiographs to assess for osteolysis, impending prosthesis failure, or cortical erosions.

Operative Indications

Vancouver Classification

- Considers location, stability of implant, and bone stock: used for postoperative fractures (Table 4.1)

Open Reduction Internal Fixation (ORIF)

- **All ORIF** should utilize biologically friendly reduction techniques, minimize soft tissue stripping and preserve vascularity to the bone in order to maximize healing potential and minimize the incidence of nonunion.
- Most failures are related to older reduction techniques with less respect for the soft tissues.
- Contraindicated with varus malalignment greater than 6 degrees due to increased rate of pseudoarthrosis.
- Utilize the original surgical scar when possible and extend proximally or distally as needed.
- **Type B1**
  - A lateral plate with proximal cables and unicortical locking screws and nonlocked bicortical distal screws—with or without cortical allograft struts.
  - Results of these techniques have been very good.
- **Type C fractures**
  - An IM nail cannot be used due to the femoral component.
  - ORIF with a lateral plate extending proximally past the tip of the femoral stem is recommended in order to reduce the stress riser effect between the proximal end of the plate and the distal end of the stem.
- **Cortical onlay strut allografts**
  - Usually tibial or femoral allograft; it is essentially a biologic bone plate; it is nonviable but useful to augment construct and increase bone stock of proximal femur.
  - They can be used alone as a single graft, a double graft, or in combination with a plate.
  - Care should be taken not to strangulate the graft or host femur with cables.

- Disadvantages are high cost, limited availability, increased risk of infection, potential for disease transmission, and larger surgical exposure.

- **Distal fixation**—at least 6 plate holes distal to the fracture should be filled with 4 or more screws; some advocate plates extending to lateral femoral condyle to protect the entire femur and reduce the risk of peri-implant fracture.

Revision Arthroplasty

- Typically for Types B^2 and B^3
- Often also require ORIF with or without allograft struts
- Severe cases of bone loss may require allograft prosthesis composite or proximal femur replacement
- **Component extraction**
  - Cement and cement plugs can be removed from the fracture site.
  - May perform an extended trochanteric osteotomy of proximal femur to allow for easier stem removal, cement removal, and accurate reaming if necessary.
  - The acetabular polyethylene liner is typically exchanged (if modular) and the stability of the acetabular component is tested.
  - If also loose, the cup should also be revised.
- **Femoral component revision**
  - The canal diameter and distal femur fragment morphology should be noted preoperatively.

Table 4.1 Vancouver Classification, as Used for Postoperative Fractures

	Trochanteric		Diaphyseal at or Just Distal to Implant			Distal
	A_G	A_L	B_1	B_2	B_3	C
Bone stock	Good	Good	Good	Good	Poor	Good
Stem stability	Stable	Stable	Stable	Loose	Loose	Stable
General treatment principles	Generally nonoperative, WBAT, symptomatic Rx. Open reduction internal fixation (ORIF) with claw plate for widely displaced or unstable fxs associated with pain, weakness or limp; bone grafting for significant osteolysis	Type AL: generally nonoperative, WBAT, symptomatic Rx. ORIF for significant medial cortex involvement compromising stability of implant	ORIF with lateral plates, cables, and/or screws with or without cortical onlay allograft; rarely need for revision arthroplasty	Revision arthroplasty with long stem with or without lateral plate fixation/cortical onlay allograft	Options include revision arthroplasty with a long stem and impaction grafting, proximal femoral allograft or proximal femur replacement (tumor prosthesis)	ORIF with dist locking plat proximal to the femoral avoid a stre between th stem

  - The most effective strategy is an uncemented, extensively porous-

    coated, distally well-fixed, long stem.
    - The stem should pass the fracture site by at least 2 widths of the diaphysis.
    - The distal fragment is reamed and the stem is inserted.
    - Use caution when reaming this fragment; be wary of the anterior femoral bow and osteopenic bone.
  - “Hand reaming” may be a safer choice.
    - The trial implant can be used to facilitate proximal fragment reduction.
    - Cables are applied.
      - A prophylactic cable should be placed at the mouth of the distal fragment prior to implant insertion.
      - Trial reduction is completed to assess leg length and stability.
      - The real femoral implant is then impacted and the cables are retensioned, crimped, and cut.
- **Distal locking technique**
  - Fracture site is bridged with the implant stem and locked similar to an IM nail distally.
  - The screws are removed once the fracture has healed (6–9 mos), so that proximal fixation of the implant can be achieved.
- **Cementing**
  - Only very rarely is a cemented long stem utilized; mainly for severely osteopenic bone.
  - Anatomic fracture reduction, cables, and careful cement pressurization will avoid extravasation.
- **Proximal femoral replacement**
  - Typically B^3s only.
  - Options include a tumor prosthesis, proximal femoral allograft, or impaction grafting with plate fixation.
  - If at all possible, preserve a sleeve of proximal host bone with soft tissue attachments to aid in stability.

- Bone healing and function are poor and complications are prevalent in these cases compared to standard revision techniques.

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HIP IMPINGEMENT AND DYSPLASIA: HIP PRESERVATION WITH ARTHROSCOPY, MINIARTHROTOMY, SURGICAL DISLOCATION, PERIACETABULAR OSTEOTOMY

RITESH R. SHAH

Introduction

Most if not all idiopathic osteoarthritis is secondary OA due to subtle structural abnormalities of the hip. Current concept of FAI dates back to the 1990s after retroverted and malunited femoral neck fractures as well as patients with slipped capital femoral epiphysis.

Anatomy and Pathoanatomy

- **Dysplasia:** Femoral head is unstable due to acetabular undercoverage and migrates to a region of less coverage (usually anterolaterally) damaging a hypertrophic labrum and causing eccentric joint loading leading to early OA.
- **CAM Type FAI:** Misshaped proximal femur due to insufficient head–neck offset or aspherical femoral head causing chondral delamination or abrasion and subsequently a labrum tear.
- **Pincer Type FAI:** Global or focal acetabular overcoverage with decreased functional ROM and repeated abutment resulting in

labrum tear and rim damage and subsequent chondral delamination.

Clinical History

- Young active adults with usually insidious onset of symptoms complaining of anterior groin pain worsened with prolonged sitting, sitting to standing transitions, walking, standing, and other activities involving hip flexion and internal rotation.
- Sites of pain are groin (88%), lateral hip (67%), anterior thigh (35%).
- Ask about childhood diseases such as Legg–Calvé–Perthes disease, SCFE, dysplasia.
- Patients may have already undergone other nonorthopedic procedures such as hernia repairs or may have been treated conservatively for "hip flexor" pain or a "groin pull."
- Usually have limitation in motion.

Physical Exam

- **Exam:** Flexion, extension, abduction, adduction, internal rotation and external rotation in 90-degree flexion, internal rotation and external rotation in extension.
- **Common provocative testing producing reproducible pain**
  - Anterior impingement test: Hip flexion, adduction, and internal rotation.
  - FADDIR test: Flexion, adduction, and IR in lateral position.
  - Patrick test groin: Hip flexion, hip abduction, and knee flexion over other knee.
  - Stinchfield: Resisted hip flexion with knee extension testing iliopsoas.
  - Anterior instability: Hyper extension and hyper external rotation (dysplasia).

- Other tests please refer to Martin HD et al.

Imaging

- Accurate AP pelvis with attention to pelvic rotation and inclination, biplanar hip radiographs, modified 45-degree Dunn view for FAI or cross-table lateral with 15-degree internal rotation, and false profile for dysplasia.
  - *Leg lengths:* Use teardrops or ischial tuberosities to correct tilt and assess.
  - *Protrusio acetabuli or coxa profunda:* Femoral head or medial acetabular wall close to or medial to ilioischial line (Kohler line).
  - *Crossover sign:* Anterior and posterior acetabular walls crossover depict overcoverage or acetabular retroversion.
  - *Alpha angle:* Center of femoral neck axis with radius of curvature at point head–neck convexity. AP view and frog leg lateral can miss this.
  - *Lateral center edge angle:* Between perpendicular line from femoral head center to acetabulum and line from femoral head center to edge of sourcil. (Normal 25–35 degrees.)
  - *Acetabular index:* Between interteardrop line and line connecting medial and lateral aspect of sourcil. (Normal 0–10 degrees.)
  - *Anterior center edge angle:* On FP view, between perpendicular line from femoral head center to acetabulum and line from femoral head center to anterior acetabulum.
- **MRA:** Preferred technique to identify labrum tears and chondral delamination when suspicious for pathology.

Operative Indications

Hip Preservation Surgical Treatment

- Goals: Relieve symptoms, improve function, improve quality of life, preserve hip joint over time.

Hip Arthroscopy

- Technically demanding, outpatient procedure, minimally invasive.
- *Anesthesia:* General with muscle relaxation and hypotensive to distract joint and maintain visualization with hemostasis.
- Custom distractor device with well-padded perineal post.
- Patient is supine (most commonly) or lateral.
- *Portals:* Anterolateral, anterior or midanterior, and posterolateral. Accessory portals as needed.
- *Central compartment:* Chondral damage treated with chondroplasty or microfracture, acetabuloplasty for pincer with high-speed burr, labrum with repair with suture and anchors or conservative labrum debridement, excision of loose bodies, ligamentum teres debridement.
- *Peripheral compartment:* For CAM lesion. Creation of capsular window, release of traction, slight hip flexion and using a high-speed burr to recreate concavity at head–neck junction. Protect lateral retinacular vessels when burring laterally.
- Additionally refer to Hip Arthroscopy Chapter in Sports Section.

Mini-Open Arthrotomy

- Usually for CAM FAI only. Often advocated to do combined open and arthroscopy to deal with acetabular rim pathology.
- Supine with fracture table for joint distraction if needed.
- Anterior incision with IM plane at sartorius and TFL, release reflected head of rectus femoris, and then arthrotomy.
- Manage acetabular rim and labral pathology with traction if doing it open. Or do it arthroscopically previously.
- Osteochondroplasty at anterior femoral head–neck junction with flexion, abduction, and external rotation. Access lateral portion with progressive extension and internal rotation.

Surgical Dislocation

- Understand vascular blood supply to femoral head before proceeding.

- Acetabular rim resection, labral resection or repair, chondroplasty or microfracture, osteochondroplasty of femoral head–neck junction, relative neck lengthening, trochanteric advancement, proximal femoral osteotomy.
- Very useful for circumferential CAM FAI (aspherical femoral head deformities)
- Lateral position, Kocher–Langenbeck incision and approach, trochanteric flip osteotomy and trochanter retraction anteriorly, Z-shaped capsulotomy, anterior hip dislocation, and femoral head displacement posteroinferiorly.
- Address acetabular rim lesion, labrum pathology, chondral injuries.
- Osteochondroplasty at femoral head–neck junction, preserve lateral retinacular vessels.
- Dynamic intraoperative testing and radiographic testing.
- Trochanteric refixation with 4.5-mm screws using radiographic guidance.

Periacetabular Osteotomy (Ganz Osteotomy, Bernese Osteotomy)

- Technically very demanding and need detailed understanding of pelvis and acetabular surgical anatomy and radiographic anatomy.
- *FAI:* Acetabular retroversion usually major, posterior acetabular wall deficiencies.
- Anterosuperior femoral head overcoverage with posterolateral acetabular insufficiency can lead to worsening instability with arthroscopic acetabular anterior rim trimming.
- Dysplasia with undercoverage usually anteriorly and laterally.
- Supine, modified Smith-Petersen approach between sartorius and TFL, reflected head of rectus femoris released, anterior arthrotomy.
- *PAO cuts:* Maintain posterior column integrity, large multiplanar correction. Ischial osteotomy, pubic ramus osteotomy, iliac osteotomy, posterior columnar osteotomy maintaining integrity, and superior posterior columnar osteotomy maintaining integrity.
- Mobilization of acetabular fragment and acetabular correction, provisional fixation with K-wires, detailed radiographic analysis to

avoid overcorrection creating iatrogenic impingement, final fixation using 4.5-mm screws.

- Dynamic hip exam to assess anterior impingement and concurrent femoral head osteochondroplasty as needed.

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TOTAL KNEE ARTHROPLASTY AND KNEE ARTHRITIS

JEFFREY A. KREMPEC

Knee Anatomy and Pathoanatomy

The normal knee mechanical axis passes from the center of the femoral head through the center of the knee to the center of the ankle. A medial displaced mechanical axis may be associated with proximal tibial varus and may result in primarily medial compartment arthritic change, sometimes with bony erosion. A lateral mechanical axis may be associated with coxa vara, a hypoplastic lateral femoral condyle, proximal and diaphyseal tibial valgus, and primarily lateral compartment degenerative changes. Collateral ligaments may become contracted with prolonged severe deformities. Femoral notch osteophytes may constrict the ACL and render it nonfunctional. The PCL may become contracted and contribute to a fixed varus or valgus deformity.

Clinical History

- TKA is performed more commonly in women.
- A history of subtotal or total meniscectomy yields predictable changes in the knee, Fairbank changes, and arthritic advancement.
- Trauma, ligament injury with resultant instability, inflammatory arthropathies, and avascular necrosis may precipitate arthritic changes.
- Pain may be global, most intense over the affected compartment, or migratory.

- Pain may worsen with weight-bearing activities, ascending/descending stairs, or other specific activities.
- Symptoms may awaken the patient at night.
- Swelling is variable and may be periodic or consistent.
- As arthritic changes progress, a flexion contracture or limited flexion may occur secondary to posterior capsular contraction or posterior condyle osteophyte formation.
- Varus or valgus deformities may progress and become fixed over time.

Differential Diagnosis

- Meniscus tear—acute onset with injury, mechanical symptoms, lack of radiographic arthritic changes
- Avascular necrosis/spontaneous osteonecrosis of the knee—insidious onset, localized pain, characteristic x-ray, and MRI changes
- Septic arthritis—acute onset of severe pain and limited motion with effusion, elevated CRP, and ESR with positive synovial fluid aspiration
- Hip pathology—arthritic changes or AVN may radiate pain to the anterior thigh or knee, always examine the hip and obtain history of groin/hip pain
- Lumbar spinal stenosis—pain with lumbar extension, standing, and walking relieved by lumbar flexion, pain may radiate over the knee and involve the thigh and calf, radiographic spondylolisthesis may be present

Physical Exam

- Inspection finds neutral, valgus, or varus alignment corresponding with the arthritic compartments.
- Joint effusion is variable.
- Tenderness over the medial and lateral compartment corresponds with arthritic changes.

- Range of motion may be normal, but mild flexion contractures of 5–7 degrees are common.
- Flexion is less commonly limited.
- Crepitus with motion is variable.
- Varus or valgus deformities may correct to neutral or be fixed when tested in 10–20 degrees of flexion.
- Always examine the leg/ankle/foot skin for venous insufficiency or diabetic ulcers.
- Perform an accurate neurologic and vascular examination on every patient.
- Take note of previous incisions, as they will impact surgical planning.

Imaging

- X-ray
  - Utilize weight-bearing x-rays whenever possible.
  - Joint space narrowing, subchondral sclerosis, subchondral cysts, and peripheral osteophyte formation are the hallmarks of arthritis.
  - Examine all 3 compartments and utilize Rosenberg view for posterior condylar changes.
  - Note any bone erosion particularly medial tibia plateau or lateral femoral condyle.
- Advanced imaging (MRI or CT) is not typically indicated but is more sensitive for early or isolated cartilage defects.

Nonoperative Management

- Mainstays of nonoperative treatment: Weight loss, NSAIDS, physical therapy, corticosteroid injections, and viscosupplementation injections.
- Unloader bracing may be effective but is infrequently tolerated by

patients.

Operative Indications

- End-stage arthritic changes in the setting of failure of nonoperative treatments in patients who are not candidates for or who do not desire high tibial osteotomy.

Implant Selection

- Cemented, hybrid fixation (cementless femur/uncemented tibia), and uncemented designs exist.
- Cemented designs are indicated in all patients.
- Uncemented designs may not be optimal in the elderly with moderate/severe osteoporosis.
- Cruciate retaining, cruciate sacrificing, and cruciate substituting designs are available and none has proven superior in the literature.
- Fixed- and mobile-bearing tibial polyethylene options are available and equivalent in the literature.

Surgical Technique

Pre-op Area

- Take a history and repeat physical exam in pre-op.
- Note flexion contracture and fixed deformities.
- Be aware of anesthesia plan, antibiotics.
- Obtain consent and mark operative site.

Procedure

- **Positioning**
  - Supine, tourniquet applied, may use full case, limited time or not used.
  - Sandbag or foot positioner affixed to bed.
- **Skin incision**

- Anterior midline; classic 2 fingerbreadths above patella to medial to tibial tubercle; minimally invasive from superior pole of patella to just below joint line

- **Arthrotomy**
  - *Medial parapatellar*—5 mm from medial tendon edge leaving cuff around medial patella along medial edge patella tendon
  - *Midvastus*—split into VMO off superomedial corner of patella, blunt dissection into VMO stopping at crossing vessels
  - *Subvastus*—capsular incision along distal margin of VMO with care to protect the MCL
- **Initial dissection**
  - Subperiosteal release of MCL to midcoronal plane, more if fixed varus.
  - Remove anterior horn of medial meniscus, ACL, ± anterior fat pad, and expose superolateral femur to visualize anterior saw cut
- **Femoral preparation**
  - Retractors over lateral plateau margin and deep to MCL
  - Typically intramedullary alignment
  - Drill hole at origin of PCL
  - Primary cut at thickness of implant, consider +2-mm cut with flexion contracture
  - *Femoral sizing*
    - Anterior referencing—sizes grow posterior with constant anterior cut and variable posterior cut, prevents femoral notching
    - Posterior referencing—sizes grow anterior with constant posterior cut and variable anterior cut, will restore posterior condylar offset
  - *Femoral rotation*
    - Align parallel to Whiteside line (line from deepest point of trochlea to most anterior point of intercondylar notch) or perpendicular to epicondylar axis (line drawn from medial to lateral epicondyle) or 3-degree external rotation to posterior condyle axis (not reliable with femoral condyle abnormalities)

    - Generally use multiple landmarks to AVOID INTERNAL ROTATION ERROR which misalign patella tracking
  - *Bone cuts*—anterior first, avoid for notching (cutting into anterior femoral diaphysis cortical bone) if notch occurs consider stemmed implant to avoid stress riser, MUST PROTECT MCL
- **Tibial preparation**
  - Retractor overs posterior tibia, lateral plateau margin, and deep to MCL
  - *Intramedullary alignment*—drill begin at medial margin of lateral tibial spine
  - *Extramedullary alignment*—align along tibial spine to center of ankle over second metatarsal
  - AVOID VARUS ALIGNMENT
  - MUST PROTECT MCL AND PATELLAR TENDON AT ALL TIMES
  - *Tibial sizing*—obtain full medial to lateral coverage avoiding overhang and undersizing
  - Align rotation with medial third of tibial tubercle
  - AVOID INTERNAL ROTATION which misaligns patella tracking
- **Soft tissue balancing**
  - Varus/valgus balancing may be done with spacer blocks or tensioners or component trials.
  - Goal is for equal rectangular space throughout the flexion to extension arc.
  - *Medial releases for varus knee*
    - Subperiosteal deep MCL release extending to posterior-medial corner if necessary
    - Release of posterior portion of deep MCL off tibia, medial epicondyle osteotomy, and transfer
  - *Lateral releases for valgus knee*
    - IT band, pie-crust LCL (extension tightness) or popliteus, posterior-lateral capsule, pie-crust LCL (flexion tightness) or lateral epicondylar osteotomy

- Once ligaments/tissue is balanced, the flexion and extension gaps may or may not match (Table 4.2).

- **Patella preparation**
  - May resurface patella, perform patelloplasty, or leave unaltered.
  - Evidence is inconclusive of which is best.
  - Patella resurfacing—attempt to reconstruct native thickness, inlay or onlay options available, cemented and uncemented available, medialize on patella, and choose size to fully cover proximal to distal extent.

Table 4.2 Soft Tissue Balancing of Ligaments and Tissues in Total Knee Arthroplasty and Knee Arthritis

	Tight in Extension	Acceptable in Extension	Loose in Extension
Tight in flexion	Resect more tibia	1) Downsize femoral component 2) Recess/balance PCL if retained 3) Increase posterior tibial slope	Downsize femoral component and augment distal femur
Acceptable in flexion	1) Resect more distal femur 2) Release posterior capsule	No changes	Augment distal femur
Loose in flexion	Upsize femoral component and resect more distal femur or release posterior capsule	Upsize femoral component	Increase polyethylene thickness or augment tibia

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Postoperative Rehab and Expectations

- **Weight bearing as tolerated** immediately postoperatively
- **Multimodal pain control:** Neuraxial anesthesia, ± indwelling femoral nerve catheter, ± infusion catheter into joint, opioids, NSAIDS, intravenous acetaminophen
- **Drains:** Inconclusive evidence for/against use of drains
- **Continuous passive motion machine:** No difference in literature when compared to therapy program
- **DVT prophylaxis**

  - Early mobilization, mechanical prophylaxis (foot pumps, SCDs, etc.), and anticoagulation (ASA, warfarin, low–molecular-weight heparins, factor Xa inhibitor, etc.) in combination are required in many postoperative protocols
  - No combination is superior to others in regard to thromboembolic prevention and bleeding risk
- **Other**
  - **Patient-specific instrumentation:** Undefined role at this time, preoperative image-guided construction of cutting blocks or pin guides
  - **Computer navigation:** Surgeon utilizes computer and surgeon-defined anatomical points intraoperatively to guide cut block alignment, size, and rotation
  - **Robotic surgery:** Surgeon utilizes robotic instruments for guided bone resection

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UNICOMPARTMENTAL KNEE ARTHROPLASTY/PARTIAL KNEE ARTHROPLASTY

RITESH R. SHAH

Introduction

There is an increased interest in procedure due to preservation of ligaments, bone, and cartilage; rapid recovery; kinematic preservation; and earlier intervention.

- 8–10% of knee arthroplasties are medial UKA in the United States
- 10–25% of patients with painful arthritis have isolated unicompartmental disease

Medial Unicompartmental Knee Arthroplasty

Indications

- Medial joint-line knee pain and no lateral joint-line pain
- Degenerative arthritis affecting medial compartment; no significant DJD (grade IV chondromalacia) in lateral compartment
- Noninflammatory arthritis and noncrystalline arthropathy
- Intact anterior cruciate ligament; minimal tibial slope if ACL mildly deficient
- Minimal medial and lateral instability
- <10 degrees of varus; passively correctable
- >90 degrees of flexion

- Flexion contracture <5 degrees
- Age and weight are controversial; although obese patients may have adverse outcomes
- No significant subchondral bone loss due to cysts or osteonecrosis; can lead to component subsidence
- Patellofemoral joint degeneration grade III or less (controversial); mobile-bearing UKA studies have shown that significant PFJ OA does not result in adverse outcomes

Clinical History and Physical Exam

- Medial joint-line pain
- Assess for alignment, ROM, flexion contractures, and ligament stability

Imaging

- X-rays: AP, 45-degree flexed knee PA, lateral, axial views. Stress radiographs.

Surgical Technique

- Anteromedial incision, medial arthrotomy, avoid excessive release
- Assessment of lateral compartment and patellofemoral joint
- Resection of notch osteophytes and peripheral osteophytes
- Minimal bony resection
- Avoid varus tibial cut and deep tibial osteotomy to prevent early loosening or tibial stress fracture
- Avoid overcorrection of mechanical axis (preferable 1–2 degrees varus) to avoid lateral compartment wear

Results

- Excellent 10- and 20-yr data; although results decrease after 15 yrs
- Common causes of failure are lateral compartment degeneration, component loosening, component malposition, and polyethylene wear

Mobile Bearing versus Fixed Bearing

- Mobile bearing has increased conformity and contact but less constraint
- Risk of bearing dislocation
- Results are similar for both bearing types

Lateral Unicompartmental Arthroplasty

Indications

- Lateral knee pain
- Isolated lateral joint OA limiting activity (no medial OA)
  - Medial PFJ OA is a contraindication
  - Lateral facet PFJ OA pain can be improved with a lateral UKA
- Intact ACL
- Flexion >90 degrees with flexion contracture <10 degrees
- Correctable valgus deformity (contraindication if fixed deformity)

Technique

- Medial or lateral arthrotomy
- Minimal tibial bony resection, position femoral component to balance flexion and extension gaps without anterior femoral overhang to prevent patellar impingement in the trochlear groove, slight internal rotation of tibial component to allow increased femoral condylar rollback
- Usually use fixed bearing as opposed to mobile bearing due to increased risk of bearing dislocation due to increased anteroposterior translation in lateral compartment

Patellofemoral Arthroplasty

Indications

- Isolated patellofemoral arthritis: No arthritis in lateral or medial compartments

- Anterior knee pain: Retropatellar or peripatellar; stairs; hills; squatting
- Contraindicated for excessive Q angles unless corrected with staged tibial tubercle realignment or simultaneous tibial tubercle realignment

Contraindications

- Inflammatory arthritis, chondrocalcinosis, joint-line arthritis or pain, flexion contractures

Clinical History and Physical Exam

- Pain at anterior knee worsening with stairs, hills, sitting to standing, and squatting
- History of trauma, patellar dislocations, previous surgical history
- Exclude other causes of pain such as quadriceps or patellar tendinitis, prepatellar or pes anserine bursitis, meniscal tears, ligamentous injuries, and tibiofemoral arthritis
- Assess patellar tracking and Q angle, patellar compression test, rule out joint-line tenderness, range of motion for full extension and excellent flexion.

Imaging

- X-rays
  - AP and 45-degree WB PA views should rule out tibiofemoral arthritis, lateral x-rays should show patellofemoral OA
  - Axial x-rays to ascertain patellar position

Technique

- Avoid incising tibiofemoral compartment and meniscus or intermeniscal ligament. Assess tibiofemoral compartments for diffuse OA; if present abandon and do TKA or do PFA and UKA.
- Ensure external rotation of trochlear component to be parallel to epicondylar axis; remove marginal osteophytes at notch.
- Ensure trochlear component does not overhang medial or lateral femoral margins or impinge intercondylar notch.

- Patellar component should be medialized, superior, and lateral facet should be removed to enhance patellar tracking and avoid impingement.
- Lateral retinacular release for patellar tilt or maltracking.

Results

- Onlay designs are better than inlay designs because they are parallel to epicondylar axis. Inlay designs tend to be internally rotated.
- Failures occur due to malposition, implant type, poor patient selection, progressive tibiofemoral arthritis, loosening, and wear.
- Results decrease substantially after 10 yrs and most common reason for revision to TKA is tibiofemoral arthritis.

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REVISION TOTAL KNEE ARTHROPLASTY

JEFFREY A. KREMPEC

Indications for Revision Total Knee Arthroplasty

- **Instability**
  - *Pain* arises from ligamentous overload and may manifest at ligament insertions
  - May have persistent bloody/blood-tinged effusions
  - Complaints of subjective instability may be in
    - extension with weight bearing
    - flexion with ascending/descending stairs or inclines
    - deep flexion with sitting
    - hyperextension with standing, or in combination
  - *Etiologies* may be
    - improper soft tissue balancing
    - ligament injury or attenuation (late PCL rupture with cruciate-retaining implant)
    - excessive bone resection at initial surgery without reconstruction
    - improper component alignment or rotation
  - *Treatment* may be
    - polyethylene exchange
    - single component revision
    - both component revision

- **Infection**
  - *Pain*
    - may be acute or chronic
    - arises from synovitis, effusions, component loosening, and osteolysis
  - *Treatment*
    - Acute Segawa type II and IV: treated with I&D and liner exchange
    - Type III is treated by 2-stage exchange arthroplasty
- **Polyethylene liner wear and osteolysis**
  - *Pain* may originate from chronic effusion secondary to synovitis from polyethylene debris
    - Osteolytic lesions in response to polyethylene debris may become large enough to cause pain with weight bearing, periprosthetic fracture, or component loosening
    - Extensive metallosis may occur with component wear through
  - *Treatment* may be debridement with polyethylene exchange or component revision
- **Aseptic loosening**
  - Loosening of either component may become painful with micro or macro motion
  - *Etiology* may be prolonged/excessive mechanical stress over time, suboptimal alignment, suboptimal cement or uncemented technique, failure of bone ingrowth/ongrowth, or osteolysis
  - *Treatment* is component revision
- **Periprosthetic fracture**
  - Revision to a stemmed component or a tumor prosthesis may be indicated
    - if the fracture caused component loosening
    - if insufficient bone for ORIF remains attached to the implant
    - patient factors make ORIF undesirable
    - if another indication for revision is present in the setting of an

acute fracture

- **Patellar etiologies of pain**
  - Unresurfaced patellae may become arthritic and painful and warrant revision to a patellar resurfacing
  - Malrotation of the femoral and tibial components may result in maltracking and pain
- **Unexplained pain:** Uncommon indication for revision surgery and worst prognosis; should be avoided if possible

Clinical History

- Revision TKA is most commonly performed for persistent pain regardless of the etiology and this is the most common complaint.
- Complaints of subjective instability, falls, mechanical sounds, and persistent weakness may indicate instability.
- Acute pain and swelling, warmth, erythema, wound healing difficulty, history of multiple surgeries, and patient risk factors may indicate infection.
- Aseptic loosening and osteolysis typically present with insidious onset of pain that intensifies over time and is worse with weight-bearing activities.
- Anterior knee pain may indicate patellar pathology, which may worsen with weight bearing in a flexed posture such as ascending stairs.

Differential Diagnosis

- Differential diagnosis includes the above-discussed etiologies.
- Lumbar radiculopathy or spinal stenosis must be ruled out if pain does not correlate with exam and imaging or radiates above or below the knee.
- Hip pathology may radiate pain to the anterior knee and must be evaluated.

Physical Exam

- Inspection finds neutral, valgus, or varus alignment.
- Joint effusion is common.
- Tenderness over the MCL and LCL origin/insertions may indicate instability.
- Varus/valgus stability should be tested in full extension and throughout the range of flexion.
- Excessive anterior/posterior translation at 90° flexion may indicate flexion instability or PCL pathology if CR implant.
- Range of motion may be normal, but mild flexion contractures or limited flexion may be present and often accompanies chronic infection.
- Evaluate the patella tracking and for crepitus during motion.
- Note previous incisions, the skin character and quality, and any draining wounds or sinus tracts.
- Always complete an accurate vascular and neurologic exam.

Imaging

- **X-rays**
  - Utilize weight-bearing x-rays whenever possible.
  - Evaluate component alignment in both AP and lateral planes.
  - Evaluate patellar tracking and femoral component rotation with sunrise view.
  - Radiolucencies at the implant/cement, cement/bone, or implant/bone interface should be examined and compared to previous x-rays whenever available.
  - Osteolysis is commonly found in the femoral condyles seen on the lateral image or in the tibial metaphysis seen on both images.
  - Examine the type of implant and design for PCL management.
  - Note the polyethylene thickness and symmetry of medial and

lateral compartments during weight bearing.

  - THE MOST HELPFUL IMAGING STUDIES ARE SERIAL X-RAYS.

- **CT scan**
  - CT is helpful for evaluating component rotation and alignment.
  - It is more sensitive for sizing osteolytic lesions.
  - It is useful with periprosthetic fractures to evaluate bone stock and suitability for ORIF vs. revision.
- **MRI**
  - Usually not helpful unless metal artifact reduction series are done.
  - May help identify ligamentous injuries or fluid collections.
- **Nuclear medicine scans**
  - May be helpful with identifying loosening or infection.
  - May be falsely positive up to one or more years postoperatively.

Lab Studies and Aspiration

- C-reactive protein (CRP) and erythrocyte sedimentation rate (ESR) should be done to screen for infection.
  - If both are negative then the likelihood of infection is low.
  - If either is elevated or clinical suspicion exists then aspirate the knee under sterile conditions.
- Synovial fluid should be analyzed for WBC with differential, Gram stain, and cultures.
- Aspiration should be done at least 3 wks after any antibiotic administration if possible to limit false-negative results.

Nonoperative Management

- If not infected, surgery is typically not mandatory or urgent and the patient may choose to treat without surgery.
- Injections are not typically indicated.

- Pain control with activity limitations or modifications, walking aids, NSAIDS, and pain medication may be satisfactory.
- Bracing for instability may help.

Implant Selection

- Revision TKA is nearly always treated with stemmed components if component removal occurs.
- Hybrid cementing technique with joint surface cement, metaphyseal cement, and cementless press-fit stems is most widely used.
- Metaphyseal, fully cemented stems and fully uncemented constructs are used less commonly.
- Porous-coated metaphyseal sleeves or porous metaphyseal cones may be used in situations of bone loss and cavitary defects.
- Bulk allografts and allograft-prosthetic composites are much less commonly used with the availability of metal augmentation.
- A goal of revision TKA is to use as little constraint as possible.
- Most commonly, posterior stabilized implants are utilized, but constrained implants and hinge mechanisms are sometimes necessary for ligamentous incompetence.

Surgical Technique

Pre-op Area

Take a history and repeat physical exam in pre-op.

- Note previous incisions and ligamentous competence.
- Be aware of anesthesia plan, antibiotics.
- Obtain consent and mark operative site.

Procedure

- **Positioning**
  - Supine, tourniquet applied, may use entire case, limited time or not used.
  - Sandbag or foot positioner affixed to bed.

- **Skin incision**
  - Anterior midline—use the previous incision and extend both proximal and distal to find normal tissue planes.
  - There is no role for minimally invasive revision TKA.
  - If multiple previous incisions exist use the lateral incision to avoid skin complications.
- **Arthrotomy**
  - Medial parapatellar—standard approach to revision TKA.
  - Minimally invasive approaches are not indicated.
- **Extensile exposures**
  - *Quadriceps snip*—oblique incision through the quadriceps tendon proximal at the myotendon junction to enhance exposure
  - *Tibial tubercle osteotomy*—long osteotomy containing tubercle and hinged on lateral soft tissues, affixed with screws or cables, may help for exposure or removing cement or well-fixed uncemented implants
  - *Tubercle peel*—less commonly used, peel of the tendon off the tubercle from medial to lateral
  - *Quadriceps turndown*—inverted-V incision in the quadriceps tendon with complete reflection distally
- **Initial dissection**
  - Subperiosteal release of MCL beyond midcoronal plane to and around the posterior-medial corner.
  - External rotation of the tibia after release will enhance exposure.
  - Fully debride medial and lateral gutters and suprapatellar pouch.
  - Perform a lateral retinacular incision with care to protect geniculate vessels to the patella.
  - Release any tethering scar deep to patellar tendon on the tibia and component.
    - This approach will provide exposure to most revision TKA scenarios.
    - If further exposure is needed, usually quad snip utilized next

followed by tibial tubercle osteotomy.

- **Component removal**
  - Fully expose the components and remove any soft tissue at the bone/implant/cement interface.
  - Utilize specialized or thin osteotomes to disrupt the bone/implant or the implant/cement interface.
    - A microsagittal saw or reciprocating saw may be useful.
    - If possible, disimpact the femur with a device attached to the condyles.
    - Avoid using mallet on the anterior flange as this often leads to bone loss.
  - Pay particular attention to the distal and posterior condylar areas as these are areas susceptible to bone loss.
  - Avoid disimpacting the tibial component until completely exposed and retraced anteriorly as premature removal may damage the femoral condyles.
  - Retained cement may be fragmented and removed with osteotomes or ultrasonic cement removal tools.
- **Femoral preparation**
  - Distal cut is made off intramedullary reamer or broach.
  - Anterior/posterior/chamfer cuts are made parallel to the epicondylar axis.
  - Consider posterolateral augmentation to avoid internal rotation of the femoral component.
- **Tibial preparation**
  - Freshening cut, if made, is based on intramedullary reamer
  - MUST PROTECT MCL AND PATELLAR TENDON AT ALL TIMES
  - Tibial sizing—obtain full medial to lateral coverage avoiding overhang and undersizing
  - Align rotation with medial third of tibial tubercle
  - AVOID INTERNAL ROTATION, which misaligns patella tracking

  - Some systems offer offset stems or rotating trays/implants to obtain optimal coverage
- **Bone loss**
  - Tibial and femoral bone loss is typically managed with metal augmentation.
  - Distal or posterior femoral augmentation is often needed as some bone loss may occur with component removal.
  - Medial tibial augmentation is common with revision of implants that fail and subside into varus.
  - Cavitary, contained bone loss may be impaction grafted with autograft or allograft bone.
  - Large defects may be treated with metaphyseal sleeves or porous metal cones.
- **Soft tissue balancing**
  - Varus/valgus and flexion/extension balance is achieved by a combination of soft tissue and joint-line management.
  - The joint line should be 25 mm from the medial epicondyle or approximately at or below the inferior pole of the patella.
  - Raising the joint line may diminish flexion and decrease the range of motion.
  - Distal and posterior femoral augmentation lowers the joint line.
  - Thicker polyethylene inserts and tibial augmentation raise the joint line.
  - Once ligaments/tissue is balanced the flexion and extension gaps may or may not match (Table 4.3).

Table 4.3 Soft Tissue Balancing of Ligaments and Tissues in Revision Total Knee Arthroplasty

	Tight in Extension	Acceptable in Extension	Loose in Extension
Tight in flexion	Downsize polyethylene and lower joint line	1) Downsize femoral component or 2) Downsize polyethylene and augment distal femur	Downsize femoral component and augment distal femur
Acceptable in flexion	1) Resect more distal femur 2) Release posterior capsule	No changes	Augment distal femur
Loose in flexion	Upsize femoral component and resect more distal femur or release posterior capsule	Upsize femoral component and augment posterior femur	1) Increase polyethylene thickness or 2) Augment tibia or 3) Augment distal and posterior femur

Postoperative Rehab and Expectations

- **Weight bearing as tolerated** immediately postoperatively unless extensile exposure dictates limited weight bearing.
- **Multimodal pain control:** Neuraxial anesthesia, ± indwelling femoral nerve catheter, ± infusion catheter into joint, opioids, NSAIDS, intravenous acetaminophen.
- **Drains:** Inconclusive evidence for/against use of drains.
- **Continuous passive motion machine:** No difference in literature when compared to therapy program.
- **DVT prophylaxis**
  - Early mobilization, mechanical prophylaxis (foot pumps, SCDs, etc.), and anticoagulation (warfarin, low molecular weight heparins, factor Xa inhibitor, etc.) in combination are required in many postoperative protocols.
  - No combination is superior to others in regard to thromboembolic prevention and bleeding risk.

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PERIPROSTHETIC FRACTURE AFTER TKA

RAVI K. BASHYAL

Introduction

Incidence of periprosthetic fracture after total knee arthroplasty (TKA) has been increasing as volume of patients undergoing TKA and subsequent revision(s) TKAs has been substantially rising. Fractures can occur intraoperatively or postoperatively (more common); this chapter will focus on diagnosis, classification, and treatment of postoperative femoral and tibial periprosthetic femur fractures after TKA.

Diagnosis

- **Intraoperative fractures**
  - Beware when reaming/impaction (especially in revision setting) suddenly goes from tight/difficult to loose/easy
  - Low threshold to obtain intraoperative x-rays with any abnormality during case, again especially in the revision setting
- **Postoperative fractures**
  - X-ray evaluation initially
  - In cases with osteolysis and/or possible stress fracture, metal suppression CT can be useful
    - Osteolysis is often underrepresented on standard AP/lateral plain x-rays.
    - CT scan can reveal true extent of cortical thinning, and possible

areas of stress fracture.

- Standing alignment films can be useful for preoperative planning in the subacute/stress fracture setting.

Periprosthetic Supracondylar Femur Fractures after TKA

- **Risk factors**
  - Systemic factors including osteopenia, RA, and neuromuscular disorders (especially those that predispose to imbalance/falls)
  - Osteolysis
  - Femoral notching (dependent on depth/severity of notch)
  - Component malposition has NOT been shown to increase risk of periprosthetic femur fracture after TKA
- **Classification:** Most commonly used is the Hornbeck, Angliss, and Lewis classification:
  - Type I: Undisplaced fracture, prosthesis intact
  - Type II: Displaced fracture, prosthesis intact
  - Type III: Displaced or undisplaced fracture with loose prosthesis, or with any other signs (instability, polyethylene wear, etc.) of failure

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Nonoperative Management

- May be acceptable in type I fractures, especially in older, medically debilitated patients
- Success rates for closed/nonoperative management decrease substantially for type II fractures
- Nonoperative management is limited by the possibility of restricted weight bearing for prolonged periods

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Operative Management

- Required for most type II fractures, and all type III
- Type II fractures can be treated by addressing the fracture alone;

however, type III fracture must also include revision of the TKA to address the loose prosthesis or other mode of failure

- Type II fractures: Open reduction and internal fixation, with or without adjunct bone grafting
- Type II fractures: Retrograde IM nailing
- Type II fractures: External fixation (less preferred)
- Type III fractures: Stemmed revision components, allograft-prosthesis composite (APC) for severe bone loss, distal femoral replacement with endoprosthesis for severe bone loss that cannot be adequately treated with stemmed components.

Periprosthetic Tibial Fractures after TKA

- **Risk factors**
  - Significant preoperative deformity
  - Systemic factors similar to risk factors for femur fracture listed above
  - In contrast to periprosthetic femur fractures, periprosthetic tibia fracture DO have an association with component malposition
  - Cementless components
- **Classification:** Felix, Stuart, and Hanssen system is based on anatomic location and component status
  - **Anatomic patterns**
    - I. Tibial plateau
    - II. Adjacent to stem
    - III. Distal to prosthesis
    - IV. Tibial tubercle
  - **Subcategory of component status**
    - A. Well fixed
    - B. Loose
    - C. Intraoperative fracture
- **Treatment**

- **Type I**
  - Usually occurs with loosening of component if post-op, treatment in these situations is revision TKA.
  - Type IC fractures (intraoperative) may occur, and if the prosthesis and fracture appear stable, may be treated nonoperatively with bracing and restricted weight bearing, if unstable they require a stemmed component to bypass the fracture site.
- **Type II**
  - IIA can be treated nonoperatively if fracture is stable and nondisplaced (or able to be successfully closed reduced), otherwise ORIF to reduce and stabilize.
  - IIB requires revision TKA, usually with a long-stemmed component, APC may be used in cases of severe bone loss.
- **Type III**
  - IIIA can be treated with casting and restricted weight bearing if stable and nondisplaced, otherwise ORIF.
  - IIIB may require initial ORIF to stabilize tibia, followed by subsequent revision TKA after healing to address loose or failed components. In some cases when the fracture is proximal enough, a long-stemmed component can be used to bypass the fracture site for a single-stage revision.
- **Type IV**
  - If stable can be treated nonoperatively with extension casting/bracing
  - If displaced or unstable, requires ORIF

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PERIPROSTHETIC JOINT INFECTIONS

JEREMY R. KINDER

Etiology

Periprosthetic infections range from 0.4–2% of all implanted total joint arthroplasties. Rate of infection within the first 2 yrs is approximately 1.5%. The rate of infection occurring from 2–10 yrs is approximately 0.5%. Risk factors for infection include diabetes, rheumatoid arthritis, malnutrition, smoking, obesity, steroids, excessive anticoagulation, chemotherapy, cancer, alcoholism, urinary tract infection, and revision surgery. Risk of infection in a diabetic patient is three times that of a nondiabetic patient.

Definition and Classification

- Periprosthetic joint infection must have one of the three following criteria.
  1. Sinus tract communicating with the prosthesis (or)
  2. Pathogen is found by culture from at least 2 separate tissue or fluid samples (or)
  3. Four of the following criteria
     a. Elevated ESR and CRP
     b. Elevated synovial leukocyte count (greater than 1,100–2,500 in knees and 2,500 in hips)
     c. Elevated synovial neutrophil count (greater than 64–80% in knees and 80% in hips)

d. Presence of purulence

e. Isolation of microorganism in one culture or periprosthetic tissue or fluid

f. Greater than 5–10 neutrophils per high-powered field in 5 high-powered fields at $\times$400 magnification

- Types of infection
  - **Type I infection**—Cultures that come back positive postoperatively following a revision where infection was not suspected.
  - **Type II infection**—Acute postoperative infections that occur within the first 4 wks following surgery.
  - **Type III infection**—Acute hematogenous occur years after implantation and are typically identified with a known source.
  - **Type IV infection**—Chronic infections that have been present for more than a month.

Signs and Symptoms

- Pain is the most common symptom.
- Any total joint replacement with new pain should be evaluated for infection.
- Recent potential sources of infection should also be identified.
- Patients will present with typically continuous pain.
  - They may have stiffness and limited motions.
  - Swelling and erythema can be present.
- Fever and malaise may be present, but these are not typical symptoms.
- A draining sinus is considered an infection until proven otherwise.
- Infection should always be suspected when radiographs note loosening particularly if the joint was implanted within 5 yrs.

Differential Diagnosis

- Inflammatory arthropathy—Gout attack. Send synovial fluid for crystal analysis.
- Hemarthrosis—this has multiple etiologies but could be from trauma, chemoprophylaxis, instability, etc.
- Inflammation from osteolysis.

Physical Exam

Pre-op

- **ESR/CRP:** This test is good for ruling out infection with sensitivity >90%.
  - If both ESR and CRP are elevated, perform an aspiration of the joint.
  - If only one is elevated in a total hip arthroplasty and no surgery is planned, a repeat ESR and CRP can be performed in 3 mos to avoid the morbidity and pain associated with a hip aspiration.
  - If one of two is elevated in a total knee arthroplasty, perform an aspiration.
- **Joint aspiration**
  - Performed using sterile technique.
  - Send synovial fluid for cell count and differential, aerobic, anaerobic, acid fast bacilli, and fungal cultures.
  - If patient has a history of gout, send the fluid for crystal analysis.
  - Patients should ideally not have received any antibiotic within at least 2 wks of an aspiration.
- **Cell counts**
  - **Type III and IV infections:** Cell count > 1,700 cell/μL (range of 1,100–3,000) or neutrophil percentage >65% is highly suggestive of infection.
  - **Type II infection**
    - No conclusive data. One study indicates that a cell count over 27,800 is highly suggestive of infection.

    - This can be supported with a CRP >95 mg/L or a neutrophil percentage $>89\%$.
- **Nuclear imaging-bone scan with labeled leukocyte imaging**
  - May be useful in patients with an abnormal ESR and CRP with a high probability of infection, but joint aspiration results are inconclusive.
  - Does not need to be included in the work-up for every joint infection.

Intra-op

- **Joint aspiration**
  - Performed if possible following skin incision prior to making the arthrotomy.
  - Same criteria as above are used for identifying infection.
- **Frozen section of peri-implant tissue**
  - 5–10 neutrophils found in 5 high-powered fields at $\times 400$ magnification is highly suggestive of infection.
  - The tissue sent should not include fibrinous material.
- **Cultures**
  - Repeat cultures should be obtained from the peri-implanted tissue.
  - 3–5 sets of cultures should be obtained.

Treatment

- **Antibiotic suppression**
  - Will not eradicate the infection.
  - Should only be used in patients with severe comorbidities and with bacteria that is sensitive to an oral antibiotic.
- **Incision and debridement and exchange of modular components**
  - Should only be considered for Type II or Type III infections.
  - Results are best when incision and drainage can be performed within 2 d of the onset of symptoms.

- Debridement attempts should not be considered when symptoms have been present for more than 4 wks.
- Success of eradicating infection is worse when *Staphylococcus* is the offending agent.
- Success rates range from 30–80%.

- **Direct exchange or one-stage exchange**
  - Involves removing all implants and cement if present, performing a thorough debridement and irrigation, and replanting final components in the same surgical setting.
  - This technique is not typically performed in North America due to high rates of failure.
  - There have been reports with success up to 70% for the treatment of infection.
- **Two-stage exchange**
  - Involves removal of all implants and cement, followed by a thorough debridement and irrigation.
  - The gold standard in North America.
  - An antibiotic cement spacer is then placed.
    - To avoid significantly altering the structural integrity of the cement, no more than 10% of the cement should consist of antibiotics.
    - For a 40-g bag of powdered cement, a typical mixture would include 3 g of vancomycin and 1.2 g of tobramycin.
    - High concentrations have been reported as well.
  - After a typical course of 6–8 wks of intravenous antibiotics, the patient is given a holiday from antibiotics.
  - ESR, CRP, and aspiration are once again performed.
    - The CRP and ESR will not likely return to normal, but there should be a downward trend in their results.
    - At the time of surgery, aspiration and frozen sections are sent.
    - The above values are once again used to determine if an infection is present.

    - If cement is used for replantation, antibiotic-loaded cement should be used.
    - Typically, commercially loaded antibiotic cement will suffice.
  - Success rates: 70–92% success rates occur from two-stage procedures.
  - Failure: Predictors of failure include methicillin-resistant Staph infections, culture-negative infections, and prolonged OR time greater than 2.5 hrs.
- **Resection arthroplasty**
  - Removal of all hardware and foreign bodies including cement.
  - Patients typically will have difficulty with ambulation and feelings of instability.
  - For infected hips, attempts should be made to keep as much neck length as possible to try to salvage attempts of ambulation.
  - In infected knees, patients will be able to sit in a more normal manner, but there is a frequent occurrence of knee pain and instability if the limb is used for transfers or ambulation.
- **Arthrodesis**
  - Typically not an option in total hip arthroplasties as there is severe bone loss.
  - This can be an option in infected total knee particularly if there is soft tissue compromise or an extensor mechanism disruption.
  - Fusion can be performed with intramedullary device, plates, or with external fixation.
  - Infection must be cleared prior to fusion with an intramedullary device or plates.
  - There are higher nonunion rates when a fusion is performed with external fixation.
- **Amputation**
  - Reserved for patients who have life-threatening sepsis, who have failed attempts at reimplantation with a total knee and arthrodesis, or when a soft tissue envelope cannot successfully be restored.

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HAND FRACTURES

KARAN SRIVASTAVA • DAVID CHEN

Introduction

X-rays in at least two planes before and after immobilization

Always assess for malrotation

Open Fractures of The Hand

- Exam
  - If policy allows, take a photo.
  - Order x-rays, check 2-point discrimination, motor function of all tendons and nerves in the zone of injury, pulses, and capillary refill.
  - If exam is pain limited perform nerve block after assessing sensation.
- Antibiotics
  - Ancef or clindamycin for Grade I and II, Grade III, include tobramycin for gram-negative coverage.
  - Barnyard injuries cover Clostridium.
- Irrigation and debridement should be performed ideally within 24 hrs.
- While controversial, bone grafting can probably be done early.
- Surgical emergencies: Compartment syndrome, replants, revascularizations, necrotizing fasciitis.

Thumb Metacarpal Fractures

Thumb Metacarpal Base Fractures

- Simple extra-articular fractures (epibasilar fracture)
  - Stable transverse fractures, treat with thumb spica cast, IP joint free.
  - Unstable fractures with angulation greater than 30°, treat with closed reduction and percutaneous fixation (CRPP) to prevent compensatory MP hyperextension
- **Intra-articular fractures**
  - ***Bennett fracture***
    - **Definition**
      - Simple intra-articular fracture of base of 1st metacarpal.
      - Volar ulnar portion of the MC base remains attached to the anterior oblique (beak) ligament.
      - Deforming forces are abductor pollicis longus (APL) (major) and thumb extensors, and adductor pollicis longus.
    - **Treatment**
      - Nondisplaced: Casting controversial. Most will pin these.
      - Displaced fractures: Reduce with axial traction, palmar abduction pronation, and pinning or screw fixation.
  - ***Rolando fracture***
    - **Definition**
      - Intra-articular and comminuted fracture of base of 1st metacarpal.
      - The fracture results in a Y-shaped configuration of the major portion of the metacarpal fragment.
      - If two large pieces, consider ORIF, otherwise CRPP or spanning ex-fix should be considered.
      - High progression to arthritis.
  - ***Gamekeeper's (chronic) and Skier's (acute) thumb***

- **Definition**
  - A complete injury to the proper and accessory ulnar collateral ligaments (UCL) of the thumb.
  - The UCL is torn or avulsed at its insertion site at the proximal phalanx of the thumb.
- **Anatomy**
  - The proper UCL of the thumb runs from the first metacarpal head to the volar aspect of proximal phalanx of the thumb.
  - The accessory is more volar and inserts on the volar plate.
- **Stener lesion**
  - In complete rupture of both the proper and accessory collaterals, the aponeurosis of the adductor pollicis muscle becomes interposed between the MCP joint and the torn UCL ligaments preventing healing.
- **Treatment**
  - Complete rupture with $>30^{\circ}$ of valgus with no end point in 0° and 30° of flexion implies the presence of a Stener lesion.
  - Treat operatively.
  - Incomplete rupture immobilize for 4 wks.

- ***Radial collateral ligament injury***
  - Less common than UCL. Treat similarly.

Lesser Metacarpal Base Fractures and CMC Dislocations

- ***Isolated Thumb CMC Dislocations***
  - Dislocation occurs in the dorsal direction.
  - Controversy about which ligaments are damaged.
  - The volar oblique ligament classically but perhaps dorsal complex more important.
    - **Treatment** is also a controversial issue.
      - If stable to flexion and adduction postreduction consider casting.

- Unstable dislocation: ligament reconstruction early vs. CRPP with late reconstruction if symptomatic.

- ***Reverse Bennett Fracture (baby Bennett)***
  - **Definition**
    - Fracture of the 5th metacarpal base.
    - Stable volar radial fragment while the proximal metacarpal fragment is pulled proximally by the extensor carpi ulnaris.
  - **Treatment** is closed reduction with cast immobilization if stable.
    - Unstable fractures consider stabilization with pins or screws.
- ***Multiple carpometacarpal dislocations***
  - Usually high energy and dorsal.
  - CRPP is usually sufficient.
- ***Metacarpal shaft fractures***
  - Fracture angulates apex dorsally—interossei deforming force.
  - Metacarpal shaft fractures also result in hyperextension at the MCP joint and pseudoclawing with decreased extension at the PIP joint. Always check for malrotation.
  - Controversial but classically the 2nd and 3rd metacarpal only tolerate 10° of angulation.
    - The 4th and 5th metacarpal tolerate 20° and 30° more can be acceptable. Some believe more can be tolerated.
  - Acceptable shaft shortening is 2–5 mm. 2-mm shortening = 6° extension lag.
  - Virtually every fixation type has been successfully described, though higher complication rate with plating versus K-wires.
- ***Metacarpal neck fractures***
  - Boxer's (Brawler's) fracture.
  - Definition: 5th metacarpal neck fracture.
  - Acceptable angulation: IF/MF: $<15°$, RF $<30–40°$, SF: 50–60°, or more.
  - Reduction: Jahss maneuver consists of flexing the MP joint and

applying a dorsally directed corrective force that will reduce the distal fragment.

  - MP block in 90° flexion or extension (Beckenbaugh) casting acceptable.
  - Intramedullary fixation usually sufficient if indicated.
- ***Metacarpal head fracture***
  - Assessment: Brewerton view to visualize: dorsum on x-ray cassette, MP's flexed 65 degrees, tube aimed 15° ulnar to radial.
  - History of fight bite mechanism frequently not relayed by patient.
  - ORIF vs. CRPP if fragments large enough.
- ***Metacarpophalangeal joint dislocations***
  - Simple (reducible) dislocation, almost all dorsal.
  - XR: Some P1 cartilage contacts MC head dorsally.
  - Do NOT simply apply traction as this may pull the volar plate between the MC and P1 and create a complex dislocation.
  - Reduction: Flex wrist and PIP joint to relax long flexors. Slide the P1 back over the head of the MC by applying volar and distal pressure at the base of P1 to try and keep the volar plate out of the joint.
  - Complete/complex (irreducible) joint dislocations have the volar plate avulsed from the MC and interposed in the joint block reduction.
  - XR: P1 in a dorsal bayonet position over the MC neck.
  - Treat with ORIF.

Proximal Phalanx Fracture and Middle Phalanx Fracture

- Most shaft fractures are stable.
  - Those without excessive angulation, rotation, or shortening can be treated with closed reduction and MCP block casting.
  - Unstable fractures should be treated surgically with CRPP versus

ORIF

- **Condylar fractures of the proximal and middle phalanx**
  - Almost all are unstable.
  - Close follow-up necessary if treating nondisplaced fractures nonoperatively.
  - Treat surgically with CRPP with at least two wires/screw or with ORIF.
- **Distal phalanx fractures**
  - Nondisplaced fractures immobilize with the PIP in extension.
  - Tuft fractures are most often associated with fingertip/nail injuries.
  - Mallet fractures of the dorsal base of P3, terminal tendon avulsion.
    - Clinically: Extension lag at the DIP.
    - $<$30% of the joint, treat with 6 wks full time, 6 wks nighttime splinting.
    - $>$30% of the joint, controversial splint versus extension block pinning.
  - FDP avulsion associated with volar P3 base fracture (Jersey finger).
    - Clinically: No DIP flexion.
    - Classification (Leddy and Packer):
      - Type 1 FDP avulsion without fracture
        - Retracts into palm, disrupts tendon blood supply
        - Treat surgically urgently within a week
      - Type II may have small bony avulsion with tendon trapped at PIP joint
        - Some vincula supply intact, may repair up to 6 wks
      - Type III large avulsion fracture trapped near DIP
        - ORIF
      - Type IV FDP avulses from large Type III fragment
        - Urgent ORIF and tendon reinsertion as blood supply disrupted

- **Proximal interphalangeal joint dislocations and fracture dislocations**
  - Simple dorsal dislocations
  - Commonly associated with small volar P2 base fracture.
  - Reduce as with MCP dislocations above by sliding the P2 base over the head of P2 to prevent entrapping the volar plate
  - If P2 base fracture $<40\%$ of joint surface, flex 10 degrees past instability (up to 30 degrees), treat with dorsal extension block splint and extend 10 degrees per week
  - Complex dislocations are treated with open reduction
  - Dorsal fracture dislocations
  - Radiographs: Look for "V" sign indicating subtle dorsal subluxation
  - If fracture fragment is greater than 40%, treatment surgically
  - Multiple options depending on fracture personality
  - Extension block pining, dynamic ex-fix, ORIF, hemihamate autograft, volar plate arthroplasty
  - Pure volar dislocations, rare, reduce and check for central tendon integrity with Elson test
  - Volar rotatory dislocations are more common
  - Usually irreducible as intact collateral causes contralateral portion of P2 to subluxate volarly and the condyle opposite the intact collateral buttonholes dorsally between central tendon and lateral band
  - Traction tightens this noose and prevents reduction
  - Attempt reduction by flexing the MP and PIP to relax the lateral band. Extend wrist to relax the extrinsic extensor mechanism.
  - Try to gently rotate the condyle out of the noose
  - Most need open reduction
  - Again remember to test for central tendon integrity with Elson test

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CARPAL INSTABILITY AND WRIST ARTHROSCOPY

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Carpal Instability

The loss of synchronous balance and alignment of the carpal bones that can result in altered wrist kinematics producing pain, weakness, and premature arthritis.

Anatomy and Kinematics

- **Carpal bones:** Wrist is composed of 8 carpal bones arranged in 2 rows.
  - Proximal row: Scaphoid, lunate, triquetrum, pisiform
  - Distal row: Trapezium, trapezoid, capitate, hamate
- **Intrinsic ligaments:** Ligaments, which attach directly between carpal bones.
  - Primary intrinsic ligaments of the proximal row are the scapholunate (SL) and lunotriquetral (LT) ligaments.
  - SL is thicker dorsally; LT is thicker volarly.
  - Ligaments help stabilize and balance the lunate against the opposing forces of scaphoid flexion and triquetral extension.
- **Extrinsic ligaments:** Between radius/ulna and carpal bones (radiocarpal ligament, ulnolunate ligament, etc.)
- **Kinematics**
  - Distal row bones are rigidly connected to the metacarpal base by stout ligaments.

- This allows the distal row to be controlled by the extrinsic wrist extensor and flexor tendons.
- Proximal row carpal bones do not have any direct attachments to the extrinsic wrist tendons.
  - They are relatively freely positioned between the distal radius and the distal row and the row is commonly referred to as an "intercalated segment."
  - Thus, its movement is controlled by the action of the distal row.
- The scaphoid and the triquetrum are thought to be the important links between the distal row and the proximal row.
  - Their motion is controlled secondary to the forces placed on them and the articulations with the distal row.

Classification

- Carpal instability dissociative—intrinsic ligaments are compromised

  A. DISI—Dorsal Intercalated Segment Instability

    i. Most common

    ii. Link between scaphoid and lunate is disrupted either from scaphoid fracture or injury to SL ligament

    iii. Leads to unopposed lunate extension

  B. VISI—Volar Intercalated Segment Instability

    i. Disruption of lunate and triquetrum relationship typically from LT ligament injury

    ii. Leads to unopposed lunate flexion

- Carpal instability nondissociative—extrinsic ligaments are involved (radiocarpal subluxation, midcarpal instability [MCI], adaptive carpal instability)
- Carpal instability adaptive—instability created in adaptation to underlying anomaly (typically a distal radius malunion)
- Carpal instability complex—some combination of more than one of the above

Diagnosis

- History
  - Patients will complain of pain, weakness, and limited motion in their wrist.
  - Oftentimes in cases of chronic instability, there is no history of specific trauma to the wrist.

Physical Exam

- SL instability
  - Watson test
    - Direct pressure on the distal pole of the scaphoid while translating the wrist from ulnar deviation to radial deviation.
    - A “clunk” will be felt secondary to the proximal scaphoid being pushed over the dorsal lip of the radius in a positive test.
- LT instability
  - LT compression test: Pushing triquetrum into the lunate from the ulnar side of the wrist produces pain
  - Ballottement test: Triquetrum is moved palmarly and dorsally against the lunate in order to assess for increased excursion compared to contralateral side
  - Shear test: Examiner produces dorsal translation to the pisiform and volar translation to the lunate to see if movement reproduces pain

Imaging

- Plain films
  - The standard views of the wrist include AP, lateral, and oblique films
  - Stress views include x-rays in terminal flexion–extension and radial–ulnar deviation as well as a clenched fist view
    - Look for abnormal scaphoid or lunate positioning on lateral terminal flexion and extension x-rays
  - Widening of SL interval >2 mm can be indicative of SL disruption (“Terry-Thomas” sign)

- "Cortical ring sign": Increased flexion of the scaphoid produces a discrete cortical ring as the scaphoid tubercle becomes collinear with the AP view
- Triangular lunate: Lunate normally appears quadrilateral on AP view, with SL disruption, may appear triangular on AP view
- Scaphoid ring will have decreased ring-pole distance
- SL angle normal is 47 degrees
  - DISI $>$ 60 degrees
  - VISI $<$ 30 degrees
- A flexed lunate in line with a flexed scaphoid is indicative of LT disruption

- CT and MRI can be helpful in ruling out other pathology
- Gold standard for diagnosis is wrist arthroscopy
  - Improved MRI quality allows MRI to be more commonly used for diagnosis

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SL Instability

SL instability is defined as disruption of SL ligament leading to independent motion between the scaphoid and the lunate. This is the most common carpal instability pattern and will produce a DISI pattern.

Diagnosis

- Patients will present with history of radial-sided wrist pain; usually with weakness and limited motion.
- Watson test is diagnostic.
- X-rays may be normal but often show increased scaphoid flexion and lunate extension with static instability.
- MRI will show disruption of the SL ligament.

Treatment

- Acute instability

- Can be treated with SL ligament repair with augmentation from dorsal intercarpal ligament
- Chronic instability
  - Requires reconstruction versus arthrodesis
  - Reconstruction of the SL ligament can be performed if there is no evidence of carpal arthritis
    i. Bone–tissue–bone constructs versus tenodesis with donor tendon
    ii. Modified Brunelli reconstruction with FCR has provided good results
    iii. Arthrodesis (scaphotrapeziotrapezoid [STT]) or scaphocapitate (SC) preferred
    iv. RASL procedure (Reduction and Association of the Scaphoid and Lunate) using a cannulated screw

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SLAC Wrist

- SL advanced collapse can occur if SL instability with a DISI pattern goes untreated and is the most common presentation of wrist arthritis.
  - Stage 1—Arthritis of the scaphoid and radial styloid
  - Stage 2—Arthritis along the entire radioscaphoid joint
  - Stage 3—Arthritis includes lunocapitate articulation; radiolunate joint tends to be spared with a SLAC wrist

Treatment of SLAC

- **Stage 1**
  - Aimed at eliminating radioscaphoid arthritis and correcting rotary subluxation of the scaphoid
  - Radial styloidectomy and partial wrist fusion (SC or STT arthrodesis)
  - SL ligament reconstruction is not advised in patients with signs of arthritis
- **Stage 2**

- Proximal Row Carpectomy (PRC) versus scaphoid excision and four corner fusion
- PRC—improved motion and decreased pain; high failure rate in patients <35 yrs; simpler procedure

- **Limited (partial) carpal fusion**
  - Scaphoid excision and four corner fusion—Fusion of capitate, lunate, triquetrum, and hamate
  - Scaphoid/triquetrum excision with lunate/capitates fusion
  - Traditionally greater grip strength
- Recently, ROM and grip strength nearly equivocal between PRC and four corner fusion
- **Stage 3**
  - Danger in performing PRC since head of the capitate is involved, therefore, consider performing scaphoid excision and four corner fusion

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LT Instability

LT ligament is the primary stabilizer of the LT joint. The volar portion of the LT ligament is the thickest and strongest.

Diagnosis

- History of ulnar-sided wrist pain; usually with weakness and limited motion
- Thought to be secondary to fall on outstretched arm with wrist radially deviated and forearm pronated
- LT compression, LT ballottement, and LT shear tests may be positive on exam
- X-rays may show scaphoid and lunate flexed and triquetrum extended

Treatment

- Acute LT instability

- Repair ligaments through separate dorsal and volar incisions
- Closed reduction and percutaneous pinning

- Chronic LT instability
  - LT reconstruction and dorsal capsule augmentation
  - LT arthrodesis

Carpal Instability Nondissociative

Defined as malalignment in the presence of proximal row stability (MCI). Commonly presents as palmar MCI, which leads to volar sag at the ulnar side of the wrist.

Physical Exam

- Wrist may clunk while being ulnarly deviated, pronated, and with axial compression.
- This is due to the proximal row snapping into extension with ulnar deviation of the carpus.

Treatment

- Includes repair, reconstruction, and arthrodesis
- Partial arthrodesis–triquetrohamate or capitohamate–triquetrohamate fusion
- Four corner fusion
- Total wrist fusion

Carpal Instability Adaptive

Most common cause is distal radius malunion with dorsal angulation, which can lead to a dorsal shift of the lunate and capitate or a flexion deformity between the lunate and capitates. An increase in dorsal tilt of the radius from 10 degrees volar to 45 degrees dorsal will increase ulnar loads from 21–67%.

Treatment

- Treatment is geared to correcting the cause, that is, the distal radius malunion, which typically corrects the carpal instability
- Treat deformities with >15 degrees of dorsal malunion
  - Corrective opening or closing wedge osteotomy of the distal radius
  - Ulnar shortening osteotomy can be performed in severe deformities, in addition to distal radius osteotomy

Wrist Arthroscopy

Wrist arthroscopy is now used to diagnose and address numerous different intra-articular pathologies within the wrist.

- Potential benefits include
  - shorter recovery time.
  - better visualization of some intra-articular pathology.
  - in-season treatment for athletes.
  - decreased risk for postoperative stiffness.
- Contraindications
  - Collagen disorders

Diagnosis

Provides a visual inspection of the articular surfaces, TFCC, intracarpal ligaments, and wrist capsule of the radiocarpal and midcarpal joints.

Therapy

- Ligamentous, synovial, or loose body debridement
- Repairs of the peripheral TFCC
- Treatment of ulnocarpal impaction syndrome including TFC debridement and distal ulnar resection
- Reduction of intra-articular fractures

    - Scaphoid fracture
    - Intra-articular distal radius fracture
- SL ligament repair
- Excision of ganglion cysts

Portals

- **Radiocarpal portals**—named for their relationship to the extensor compartments
    - 1–2 portal
        - Anatomic snuffbox between the EPB and EPL tendon
        - Used for radial styloidectomy
        - Very close to the radial artery and dorsal sensory branch of the radial nerve
    - 3–4 portal
        - Between the EPL and EDC tendons, 1 cm distal to Lister tubercle, just proximal to the SL interval
        - Used as the primary viewing portal
        - No underlying vessels or nerves
    - 4–5 portal
        - Located between the ED and EDQ tendons at the insertion of the TFCC into the radius
        - Primary portal for probing and debridement
        - No underlying vessels or nerves
    - 6R portal
        - Located between the EDQ and ECU distal to the ulnar styloid
        - Viewing portal for the LT ligament and ulnar aspects of the TFCC
        - Branches of the dorsal sensory branch of the ulnar nerve are at risk with this portal
    - 6U portal
        - Located ulnar to the ECU tendon

- Primarily used as an outflow portal
    - Dorsal sensory branch of the ulnar nerve is at risk with this portal
  - Palmar
    - Between the radioscaphocapitate and long radiolunate ligaments
    - Visualizes palmar portion of the SL ligament and assists with intra-articular distal radius fractures
    - Radial artery and palmar cutaneous branch of the median nerve at risk
- **Midcarpal portals**
  - Radial midcarpal portal
    - 1 cm distal to 3–4 portal
    - Visualizes distal pole of scaphoid, SL ligament, proximal pole of capitate and scaphotrapezoid joint
  - Ulnar midcarpal portal
    - 1 cm distal to the 4–5 portal
    - Visualizes the LT articulation and the triquetral-hamate articulation
  - STT portal
    - Ulnar margin of EPL between ECRL and ECRB
    - Dorsal sensory branches of radial nerve at risk
- **DRUJ portals**
  - Proximal DRUJ
    - Between the EDC and EDQ; proximal to ulnar head at the sigmoid notch
  - Distal DRUJ
    - Between the EDC and EDQ; between the ulnar head and TFCC

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HAND TENDON INJURIES

ROBERT R. L. GRAY

Extensor Tendon Injuries

Extensor tendon injuries are very commonly the result of avulsion or laceration and are typically well treated with immobilization alone for avulsions and surgical repair and immobilization for lacerations. As the extensor tendons do not pass through long fibroosseous funnels like the flexor tendons, they are less prone to problematic scarring and stiffness.

Anatomy

- There are 6 fibroosseous extensor compartments at the level of the distal radius.
  - The first contains the abductor pollicis longus and the extensor pollicis brevis.
  - The second contains the radial wrist extensors—extensor carpi radialis longus and brevis.
  - The third is another thumb compartment and contains only the extensor pollicis longus.
  - The fourth compartment contains the extensor indicis proprius and the extensor digitorum communis.
  - The fifth is for the fifth finger and contains the extensor digitorum quinti or minimi, depending on nomenclature.
  - Finally, the sixth compartment contains the ulnar wrist extensor, the extensor carpi ulnaris.
- The EPL makes a 45-degree radial turn at Lister tubercle and is prone to injury during surgical approaches and both operative and nonoperative treatment of distal radius fractures.

  - The tendons of the fourth compartment have interconnections called juncturae tendinae at the level of the metacarpal necks that can help stabilize the tendons and can also transmit extension power to a cut tendon from an adjacent tendon if the laceration is proximal to the junctura.
- As the digital extensors cross the MCP joint, they are stabilized by the sagittal bands, which prevent subluxation during motion.
  - The central tendon divides into 2 lateral bands and a central slip over the proximal phalanx.
  - It should be noted that there are no direct insertions onto the proximal phalanx and extension at the MCP occurs through the extensor hood at the MCP joint capsule.
  - Only the extrinsic extensors extend the MCP, as the lumbricals flex the MCPs as they extend the IP joints.
- The lateral bands receive contributions from the lumbrical insertions and are stabilized by the triangular ligament.
  - Damage to this ligament from trauma or inflammatory arthritis leads to volar subluxation of the lateral bands and a boutonniere deformity.
  - The lateral bands rejoin the central slip over the middle phalanx and insert on the distal phalanx in the terminal slip.
  - A disruption of the extensor mechanism at this level can lead to overpull at the PIP joint and a swan-neck deformity.

Mallet Fingers

- Avulsions from the terminal slip insertion on the distal phalanx are known as mallet injuries.
  - These can occur with or without a bony avulsion, best visualized on a lateral radiograph of the digit.
- While some advocate surgical treatment of mallet fractures, the literature supports nonoperative treatment with nearly identical outcomes to pure tendinous avulsions.
- Very rarely, when the fragment encompasses a significant portion of

the articular surface of the distal phalanx and the joint subluxates volarly, is surgical treatment indicated.

Nonoperative Treatment

- Mallet fingers are usually treated by a period of immobilization of the DIP joint only for a period of 6 wks.
- Many surgeons then follow with an additional period of 6 wks of nighttime only splinting, though recent data suggest that the first 6 wks alone are sufficient.

Operative Treatment

- Mallet fingers may be pinned in extension percutaneously to help keep the joint reduced and to reduce any associated mallet fracture.
- The avulsed fragment is often too small to fix directly and is kept in place with a dorsal blocking pin.
- In chronic injuries without any bony involvement, open treatment with a dermatotenodesis is performed to help the tendon scar back into a nearly anatomic location. There is a high rate of complication with pinning the DIP joint, which has been reported to be as high as 40%.

Digital Extensor Tendon Injuries

Lacerations in extensor zones 2–4 are more prone to stiffness after repair than those in zone 1 (over the DIP) and zones 5 (over the MCP), 6 (over the metacarpal), 7 (over the wrist), and 8 (proximal to the radiocarpal joint).

- All are treated with primary repair when possible and tendon grafting when gaps exist.
- Unlike with flexor tendon injuries in the fibroosseous sheath, staged reconstruction is not typically necessary.
- As extensor tendons are typically more broad and flat than flexor tendons, epitendinous sutures as an augmentation to core sutures are not typically used, but some surgeons use them as their primary repair stitch.

Flexor Tendon Injuries

Flexor tendon injuries are most commonly the result of laceration, but in zone 1 can be caused by avulsion from the distal phalanx.

- Unlike with extensor tendon avulsions, there is almost never a role for nonoperative treatment in healthy or active patients.

Anatomy

- The digital flexor tendons pass through several different zones, beginning at the FDP insertion on the distal phalanx and progressing proximally to the myotendinous junction.
  - Zone 1 is from the FDP insertion to the FDS insertion.
  - Zone 2 is the area in the flexor sheath where both FDS and FDP are present.
  - Proximal to the A1 pulley, zone 3 runs to the distal end of the transverse carpal ligament.
  - Zone 4 is synonymous with the carpal tunnel.
  - Zone 5 is all the tendons proximal to the transverse carpal ligament.
- The FDS tendon decussates and the 2 slips change their relative position from anterior to the FDP tendon to a direct posterior position at the level of their insertion on the middle of the middle phalanx.
- The opening that allows for passage of the FDP tendon is known as Camper chiasm.

Zone 1 FDP Avulsions (Jersey Finger)

- Avulsions from the FDP insertion at the distal phalanx are commonly known as jersey fingers as they are often sustained when the patient pulls against the jersey of a player while trying to make a tackle.
- Leddy and Packer classified these injuries based on the level of retraction of the tendon into the finger or palm.
  - Type 1 avulsions are completely stripped of vascularity and retracted into the palm.

  - Type 2 injuries are tethered by the vinculum profundus longus and are typically found at the level of the PIP joint.
  - Type 3 injuries have an associated bony avulsion and that fragment prevents the tendon from retracting past the DIP joint.
  - A fourth type was added later that includes both a bony avulsion, as well as an avulsion of the tendon from the fragment.
  - These injuries require surgical repair within 1–2 wks.

Zone 2 Flexor Tendon Injuries

- Like zone 1 injuries, these occur within the fibroosseous flexor sheath, but as both the FDP and FDS tendons are present, the risk of adhesion is even higher.
- Strong primary repair and immediate precise postoperative therapy are of paramount importance for a good outcome.
- The number of core strands crossing the repair site as well as the use of an epitendinous stitch have been demonstrated to increase repair strength.
- Flexor tendon lacerations with concomitant neurovascular injuries fare worse than isolated tendon injuries.
- Many surgeons, when faced with a laceration of the FDP and both slips of FDS, will elect to repair FDP and only one slip of FDS, while debriding the other slip.
  - This allows for more room within the tendon sheath and lower work of flexion, which can enhance the overall outcome.
- Rehabilitation protocols focus on early passive or active motion to prevent adhesions without causing gapping or rupture at the repair site.
- Historically, zone 2 was referred to as “no-man’s land” by Bunnell as attempts at repairs were met with such stiffness and disability that nonoperative treatment was preferable.

Proximal Flexor Tendon Injuries

- Zone 3 is the area between the A1 pulley and the carpal tunnel.
- Zone 4 is the carpal tunnel.

- Zone 5 is the entire course proximal to the transverse carpal ligament.
- Repairs in any of these zones typically fare much better than in zone 2 and may be immobilized initially to allow for healing.

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COMPRESSION NEUROPATHY OF THE UPPER EXTREMITY

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Carpal Tunnel Syndrome

Epidemiology and Etiology

- Carpal tunnel syndrome has an annual prevalence of over 376 cases per 100,000 persons. It is more commonly seen in the elderly, females, and individuals with a high BMI.
- Idiopathic compression of the median nerve within the carpal tunnel results in the manifestation of clinical signs and symptoms.

Physical Exam

- Common symptoms include pain, hand clumsiness, as well as paresthesia and hypoesthesia along the median nerve distribution.
- These symptoms usually worsen at night and upon exertion.
- Later signs of carpal tunnel syndrome include thenar muscle wasting and expanded two-point discrimination.

Differential Diagnosis

- **Durkan test:** Press thumbs for 30 s over the carpal tunnel; positive sign when paresthesia or pain is elicited; most sensitive (89% sensitivity)
- **Phalen test:** Wrists are in full palmar flexion and the patient experiences numbness within 1 min (50% sensitivity, 75% specificity)
- **Reversed Phalen test:** Reversal refers to the full dorsiflexion of the wrists

- **Tinel sign:** Percussion of the palmar ligament with the wrist relaxed elicits paresthesia along the median nerve distribution; least sensitive and least specific (23% sensitivity, 71% specificity)

Electrodiagnostic Testing

- Though no "gold standard" diagnostic test exists, electrophysiologic testing is the most widely accepted.
- Nerve conduction velocity (NCV)
  - An NCV test with distal sensory latency greater than 3.2 ms or a motor latency greater than 4 ms confirms median nerve compression while a negative result does not rule out carpal tunnel syndrome.
  - Comparison sensory testing has greater sensitivity and specificity than absolute sensory testing.
  - Furthermore orthodromic sensory nerve conduction studies are more sensitive than antidromic testing.
- Electromyography (EMG): Sharp waves, fibrillations, and decreased insertional activity are potential pathologic findings

Imaging

- Ultrasonography, CT, and MRI have similar diagnostic accuracy.
- When compared to EMG testing, imaging is less specific and sensitive.
- Imaging of the cross-sectional area of the distal median nerve at the pisiform level yields the greatest diagnostic accuracy.
- Cross-sectional areas greater than 0.11 mm^2 for ultrasonography, 0.12 mm^2 for CT, and 0.12 mm^2 for MRI are likely indicative of carpal tunnel syndrome, as the nerve swells distal to the site of compression.

Nonoperative Treatment

- Wrist splinting, activity modification, NSAIDs, and steroid injections are most commonly used for initial treatment.
- Conservative treatment is associated with an improvement in symptoms for 82% of patients, though 80% will have a recurrence

within 1 yr requiring surgical intervention.

Operative Indication

- Indications for surgical management include failed nonoperative treatment, persistent numbness, elevated motor weakness, or increased distal latency.
- The open and endoscopic techniques each relieve compression of the median nerve by releasing the transverse carpal ligament.
- Care must be taken not to injure the recurrent motor branch of the median nerve, which innervates the thenar muscles and passes through the transverse carpal ligament in 18% of cases.

Postoperative Rehab and Expectations

- Surgical management relieves symptoms more than conservative treatment.
- Endoscopic and open techniques have high success and patient satisfaction rates (89% and 84%, respectively).
- Due to the less invasive nature of the endoscopy and technique, it is in some studies associated with less time to return to work (12 d) than the open surgery procedure (21 d).
- **Revision rates**
  - The success rate for revision surgery is 84%, with a greater patient satisfaction rate for the endoscopic technique.

Cubital Tunnel Syndrome

Etiology and Epidemiology

- Cubital tunnel syndrome is the second most common nerve compression syndrome of the upper extremity (following carpal tunnel syndrome).
- Most commonly, it is idiopathic, but sometimes due to trauma or anatomic anomaly.

Differential Diagnosis

- Patients experience pain in the upper extremity, paresthesia and numbness along the ulnar distribution in the hand, dysthesia along the distribution of ulnar dorsal sensory branch, especially at night.
- Late findings include weakness in muscles supplied by the ulnar nerve (including reduced pinch strength).

Physical Exam

- Symptoms may be reproduced through flexion of the elbow. Late signs include wasting of the ulnar innervated muscles of the hand
- **Tinel sign:** (percussion test) over the ulnar nerve in the cubital tunnel (70% sensitivity, 98% specificity)
- **Elbow flexion test:** Maximal passive flexion of the elbow with the wrist and shoulder in neutral position elicits paresthesia along the ulnar nerve distribution (75% sensitivity, 99% specificity)
- **Froment sign:** Flexion of the distal phalanx of the thumb (AIN-innervated FPL) in an attempt to demonstrate key pinch strength.
  - Weakened ulnar-innervated interossei and adductor cannot fire and thumb flexion is used to compensate.
- **Wartenberg sign:** Ulnar deviation of the small finger with attempted adduction.

EMG/NCV Testing

- NCV: Abnormal conduction when the velocity is less than 50 m/s, or when compared to the contralateral side there is a 10 m/s difference or 20% reduction in amplitude.

Nonoperative Treatment

- Conservative management including splinting, steroid injection, activity modification, and physical therapy are beneficial in 90% of patients.
- This is the 1st line of treatment in mild cases of cubital tunnel syndrome.

Surgical Technique

- Indicated when conservative treatment fails.

- Simple decompression
  - Release Osbourne ligament, as well as the FCU superficial and deep fascia while the ulnar nerve is not dissected from its surrounding connective tissue.
  - A major concern is avoiding braches of the medial antebrachial cutaneous nerve.
- Subcutaneous transposition
  - Move the ulnar nerve anterior to the elbow axis of flexion to decrease the tension on the nerve.
  - Concerns include compromising the blood supply to the nerve and creating additional sites of decompression.
- Submuscular transposition
  - The ulnar nerve is released in the same manner used in subcutaneous transposition.
  - After the flexor–pronator muscle is incised 1–2 cm, the ulnar nerve is placed parallel to the median nerve and the reflected flexor–pronator muscle is repaired over the transposed ulnar nerve.
  - Concerns arise because this is the method requires the largest incision and most extensive dissection.
- Endoscopic technique
  - A space is made between the fascial covering of the nerve in the cubital tunnel and the subcutaneous adipose tissue to permit dissection of fascial constrictions over the ulnar nerve.

Postoperative Rehab and Expectations

- 93% of patients who have simple decompression are asymptomatic postoperatively; anterior transposition is successfully used to revise symptomatic postoperative cases.
- Sensory symptoms improve in 96% of endoscopic patients.
- Normal muscle function is reported in 90% of patients who undergo subcutaneous transposition while normalized 2-point discrimination is seen in 84% of submuscular transposition patients.

Guyon Syndrome

Etiology and Epidemiology

- Compression of the ulnar nerve in Guyon canal is rare and usually idiopathic.
- Anomalous muscles (i.e., aberrant FCU or duplication of hypothenar muscles) or abnormal structures (i.e., swellings) within the canal are additional potential sources of compression.
- It can also be caused by trauma at the base of the hypothenar eminence or the subsequent edema, causing increased pressure on the ulnar nerve.

Differential Diagnosis

- Pain in the hand or forearm along with weakness, paresthesia, and/or hypoesthesia along the ulnar nerve distribution in the hand.
- Varying patterns of neurologic deficits include
  1. pure ulnar sensory deficit,
  2. motor deficit (ulnar innervated intrinsic muscles with or without involvement of the hypothenar muscles and abductor digiti minimi), or
  3. both sensory and motor deficit (ulnar-innervated intrinsic muscles with or without involvement of the hypothenar muscles).
     - If the interosseous and adductor pollicis muscles are weak or paralyzed then the deep motor branch of the ulnar nerve is affected.
     - If the hypothenar muscles are also involved, then the ulnar nerve compression is proximal to this branch.

Physical Exam

- Muscle wasting of the first dorsal interosseous muscle indicates compression of the deep motor branch of the ulnar nerve.
- If the hypothenar muscles are also atrophied, then the ulnar nerve is compressed before the branch.

EMG/NCV Testing

- Nerve conduction will be slowed from the wrist to the first dorsal interosseous muscle

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Nonoperative Treatment

- Nonoperative treatment is the first line of treatment in most cases through splinting, activity modification, or steroid injections.

Surgical Technique

- Surgical exploration is indicated in cases with motor loss and unsuccessful nonoperative treatment.

Postoperative Rehab and Expectations

- 96% of patients treated surgically had improved motor branch injury.
- 83% have improved sensory results.

PIN Syndrome

Etiology and Epidemiology

- Posterior interosseous nerve (PIN) syndrome occurs when there is sufficient compression on the PIN, which branches from the radial nerve proper.
- The PIN may be compressed by anatomic structures such as the extensor carpi radialis brevis (ECRB), radial recurrent vessels at the radial neck ("leash of Henry"), fibrous bands anterior to the radiocapitellar joint, or most commonly by the distal or superficial proximal edge (arcade of Frohse) of the supinator.
- Other sources of compression include benign tumors (most commonly lipomas or ganglia), vasculitis, and synovitis associated with rheumatoid arthritis resulting in subluxation of the radial head.

Differential Diagnosis

- Pain along the distribution of the PIN is commonly the first complaint.

- The patient will complain of an inability to extend the fingers and weakness upon extension of the wrist.
- Radial tunnel syndrome presents with pain without loss of motor function.

Physical Exam

- Weakness and paralysis in some or all of the muscles innervated by the PIN (EDC, ECU, EDQ, ABL, EPB, EPL, EIP) with sparing of the ECRL will lead to radial deviation of the wrist on extension.
- An attempt to extend the fingers will typically lead an inability to fully extend the MCP joints.
- No loss of sensation should occur, as this would indicate a lesion of the radial nerve proximal to the PIN.

EMG/NCV Testing

- EMG will typically reveal increased distal latency in the radial nerve and denervation of paralyzed muscles.

Imaging

- MRI may assist in identifying compressive structures and masses.

Nonoperative Treatment

- Wrist splinting, anti-inflammatory medication, and activity modification is initially recommended. A steroid injection may also be used. Patients often get progressive return of individual muscles.

Surgical Technique

- Surgery is indicated in cases without motor improvement after 3–6 mos of conservative treatment.
- Surgical decompression should aim to free the PIN from compressive masses or anatomic structures.
- Early active range of motion is allowed.
- Reported success rates for surgical decompression for patients with PIN syndrome ranges from 75–94%.

Pronator Syndrome

Etiology and Epidemiology

- Pronator syndrome is due to proximal compression of the median nerve.
  - The most common site of compression is between the two heads of pronator teres.
- Other compressive structures include
  - the ligament of Struthers,
  - proximal edge of FDS arch,
  - anomalous muscles (such as Gantzer muscle), and
  - accessory tendons from the FDS to the FPL.
- Less than 1% of median nerve compressive neuropathies are due to pronator syndrome.
- Behind carpal tunnel syndrome, it is the second most common cause of median nerve entrapment.
- Pronator syndrome is mostly seen in occupations where the forearm becomes hypertrophied.

Differential Diagnosis

- Patient will experience numbness and paresthesia along the median nerve distribution in the hand.
- Unlike carpal tunnel syndrome, patients usually do not have nocturnal complaints.
- Also, they have numbness in the territory of the palmar cutaneous branch of the median nerve, which is absent in CTS.

Physical Exam

- Positive Tinel sign at the proximal ⅓ of the forearm or just proximal to the antecubital fossa (negative Tinel sign at the wrist).
- Elicit symptoms by stressing the three structures likely to be compressed
  1. pronator teres via resisted pronation of forearm with forearm in

neutral position,

2. lacertus fibrosus via resisted flexion of the elbow and supination of the forearm, or
3. the proximal edge of the arch of FDS via resisted flexion of the middle finger PIP joint.

EMG/NCV Testing

- Motor and sensory studies may show no change in the conduction because compression of the median nerve is intermittent.
- EMG of muscles served by the median nerve should be done.

Nonoperative Treatment

- Splinting (arm in pronation with slight wrist flexion, with or without flexion of the elbow) as well as NSAIDs and corticosteroids have been shown to be effective conservative management options.

Surgical Technique

- Surgical decompression is indicated in the case of failed conservative treatment or when a space-occupying lesion is present.
  - Hemostasis is imperative during median nerve decompression to minimize a postoperative hematoma.
- Procedure
  - A lazy-S-type incision is made to permit exploration of the median nerve.
  - This allows for proximal identification of the median nerve and release proximal to the antecubital crease, if necessary.
  - The median nerve is then released from the remaining compressive structures (lacertus fibrosus, humeral head of pronator teres, proximal edge of FDS arch, accessory muscles, and accessory tendons).

Postoperative Rehab and Expectations

- Surgical treatment is successful in 85% of cases.

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TENDINOSIS AND TENDINITIS

JARED CRASTO • ROBERT R. L. GRAY

Trigger Finger Tenosynovitis

Pathoanatomy

- Caused by mismatch in volume of tendon sheath at A1 pulley and its contents in the digital flexor mechanism.
- Traditionally thought to be due to thickening of the A1 pulley, but macroscopic changes of the tendon have also been observed.

Presentation

- Triggering—snapping back and forth of finger caused by stenosis of the tendon sheath.
- Clicking, grinding, catching, or locking with flexion or extension of the finger.
- Some patients may not have the above, but will have pain at the A1 pulley.
- Finger can sometimes be locked in flexion.
- Usually mild swelling/tenderness at area palmar to A1 pulley (located volar to MCP joint).
- Tendinous nodule can be palpable in this area as well.

Etiology

- Usually idiopathic, but can also be seen with the following diseases:
  - Rheumatoid arthritis
  - Diabetes
  - Gout

- Carpal tunnel syndrome
- de Quervain tenosynovitis
- Dupuytren contracture
- Hypertension
- Amyloidosis
- Mucopolysaccharidosis

Nonoperative Treatment

- *Activity modification*—refrain from heavy gripping activities (i.e., hammering).
- *Splinting*—hold MCP joint in neutral extension or 10–15° of flexion (4+ mo).
- *NSAIDs*—reduction of swelling may benefit patient.
- *Steroid injections*—can use up to 3 injections, 42–97% effective.
- Efficacy diminished in patients with diabetes.
- Patients with diabetes warned that hyperglycemia can occur, lasts 5 d.
- *Physiotherapy*—wax therapy, ultrasound, stretching, exercise, and massage of muscles; up to 68% effective.

Operative Treatment

- *Open surgery*—complete release of A1 pulley. If necessary, C1 pulley is released, and sometimes even ulnar slip of FDS. 97% effective.
- *Percutaneous surgery*—uses needles to release the pulleys described above. Theoretically higher risk of neurovascular injury. Equally successful to open surgery.

De Quervain Tenosynovitis

Pathoanatomy

- Thickening of extensor retinaculum of first extensor compartment, affecting the included tendons: abductor pollicis longus (APL) and extensor pollicis brevis (EPB).

- Most common finding is thickening in first extensor compartment, around subsheath of EPB.

History/Presentation

- Radial-sided wrist pain of insidious onset; exacerbated by lifting objects with wrist in neutral rotation and/or with prolonged thumb extension.
- Swelling/tenderness of 1st extensor compartment. Nodule can also be present in the area.

Physical Exam

- Finkelstein test
  - Hold patient's thumb in flexion and fingers in partial flexion and ulnarly deviate wrist.
  - If the pain elicited is the same the patient feels, this is a positive test.
- Eichoff maneuver
  - Have patient make fist with thumb included, then ulnarly deviate.
  - If the pain elicited is the same the patient feels, this is a positive test.

Etiology

- Unclear, the following theories have been proposed:
  - Repetitive lifting and manipulation
  - Trauma
  - Increased frictional forces
  - Anatomic abnormality
  - Biomechanical compression
  - Repetitive microtrauma
  - Inflammatory disease
  - Increased volume states (i.e., pregnancy)

Nonoperative Treatment

- *Activity modification*—minimize activities involving prolonged thumb extension and/or radial deviation of the wrist.
- *Thumb spica splints*—when combined with NSAIDs, effective in 88% of patients with minimal symptoms, only 32% of patients with moderate symptoms.
- *NSAIDs*—indicated especially for mild symptoms and if patient declines a steroid injection.
- *Steroid injections*—success rates range from 62–93%. When used in conjunction with splint can improve efficacy of splint alone.

Operative Treatment

- Open Surgery—complete release of 1st extensor compartment, 91% successful.

Intersection Syndrome

Pathoanatomy

- Tendons of 2nd extensor compartment pass underneath tendons of 1st extensor compartment, this area can become inflamed, which can lead to inflammation of the tendons (tendinitis), or inflammation of the tendon sheath (tenosynovitis).

History/Presentation

- Pathognomonic—pain, edema, and crepitus found 4–8 cm proximal to the radial styloid.
- Pain and swelling over the dorsal radial aspect of the forearm, about 4 cm proximal to the wrist.
- Severe cases may present with redness and leathery crepitus.
- Note that this differs from de Quervain tenosynovitis in that the pain is located in the 2nd dorsal compartment, 4–8 cm proximal to the radial styloid.

Etiology

- Unclear, but three theories have been proposed:
  - Friction between muscle bellies of APL and EPB with tendon sheath that contains ECRL and ECRB, possibly causing tenosynovitis.
  - Pure form of tendinitis.
  - Stenosis of the 2nd dorsal compartment.

Nonoperative Treatment

- *Activity modification*—immobilization with splint that keeps wrist in 15° of continual extension.
- *NSAIDs*—reduction of swelling may benefit patient.
- *Physical therapy*—focusing on range-of-motion exercises and wrist extensor strengthening may be beneficial.
- *Steroid injections*—indicated if patient doesn't respond to conservative therapy as listed above.

Operative Treatment

- Release of the tendon subsheath surrounding the 2nd extensor compartment (ECRL/ECRB).

Extensor Carpi Ulnaris (ECU) Tendinitis

Pathoanatomy

- Stenosing tenosynovitis of the 6th extensor compartment.

History/Presentation

- Pain and swelling along dorsal ulnar aspect of the wrist.
- Crepitus is present occasionally.

Physical Exam

- ECU synergy test
  - Patient rests arm on exam table with elbow flexed to 90° and forearm in full supination.
  - Wrist held in neutral position, fingers in full extension.
  - Examiner grasps patient's thumb and long finger with one hand, palpates ECU tendon with other hand.
  - Patient then radially abducts thumb against resistance, presence of both FCU and ECU muscle contraction confirmed by direct palpation as tendon bowstrings under the fingertips.
  - Recreation of pain along dorsal ulnar aspect of wrist is considered positive for ECU tendinitis.

Etiology

- Unclear but two theories exist:
  - Secondary manifestation of TFCC pathology. Should be suspected if conservative treatment is ineffective.
  - Anomalous tendon slip from the ECU to extensor apparatus of small finger induces secondary ECU tendinitis.

Nonoperative Treatment

- Splinting, anti-inflammatory agents, and corticosteroid injection are almost always successful if implemented during the acute stages of inflammation.

Operative Treatment

- Indicated if tendinitis of 6th dorsal compartment progresses to fibrosis.
- ECU is held in a bony trough of the ulna by a substantial subsheath that is separate and distinct from the extensor retinaculum.
  - This subsheath must be divided to decompress the tendon, it is recommended this be released at the radial-most edge.

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HAND INFECTIONS

SOFIA ZENTENO • ROBERT R. L. GRAY

Organisms

- The most common organism causing the overall spectrum of hand infections includes the following:
  - *Staphylococcus aureus* is most common organism causing 50–80% of hand infections.
  - *Streptococcus spp.* are the next most common organisms isolated.
  - Gram-negative organisms and anaerobic bacteria are seen in IVDA, DM, farm injuries, bite wounds (*Pasteurella multocida* mainly seen with animal bites and *Eikenella corrodens* seen commonly with human bites).
- Other: Atypical mycobacterium and/or fungi are specifically seen in chronic indolent infections or the immunocompromised host.

Herpetic Whitlow

Definition

- Herpetic whitlow results from autoinoculation of type 1 or type 2 HSV into broken skin.

Organism

- The most common viruses isolated are Herpes simplex virus (HSV) types 1 and 2.

Presentation

- Usually presents 2–14 d after exposure with tingling and burning pain of the hand that is disproportionate to the clinical findings associated with influenza-like symptoms, including fever, lymphadenitis, epitrochlear, and axillary lymphadenopathy.

Natural History

- It is a self-limiting condition that usually resolves in 2–3 wks but that can recur specially under conditions such as stress, sun exposure, fever, etc.
- HSV avoids immune clearance by harbor in latent stage within the nervous ganglia.

Differential Diagnosis

- It is usually a clinical diagnosis, although cultures (taking 1–5 d)
- A Tzanck smear (less sensible than a viral culture) can be done as well.

Treatment

- Due to its self-limited course, this condition should only be observed and symptomatically treated with pain medication.
- Patients involved in health care, especially dentists and respiratory therapists, should wear a finger covering or avoid manipulating patients with the affected extremity.
- Acyclovir may decrease the duration of the disease and can prevent recurrences.

Flexor Tenosynovitis

Organism

- Causative agents for flexor tenosynovitis typically include *Staphylococcus* and *Streptococcus* species.
- Mixed infections should be suspected in patients who have diabetes or are immunocompromised.
- Disseminated gonorrhea and *Candida albicans* infection have been reported as causes of flexor tenosynovitis.

Physical Exam

- Patients with pyogenic flexor tenosynovitis present with the four cardinal signs as described by Kanavel:
  1. uniform, symmetric digit swelling
  2. at rest, digit is held in partial flexion
  3. excessive tenderness along the entire course of the flexor tendon sheath, and
  4. pain along the tendon sheath with passive digit extension.
- Pain with passive extension has been reported as the most clinically reproducible of these four signs.

Treatment

- Depending on the clinical stage of the disease, two treatment approaches are usually followed.
  - In the early phase intravenous antibiotics should be used for 24 hrs, followed by reassessment.
  - In the late phase, when the patient has an established infection, limited incision and catheter irrigation (provided able to flush) should be warranted.

Complications

- The main complications following this condition are extension of the infection to the Parona's, thenar and midpalmar spaces, and stiffness.
- Stiffness is an incapacitating long-term sequelae of flexor tenosynovitis.

Collar Button Abscess

Organism

- As with most hand injuries, *Staphylococcus* and *Streptococcus* remain the most common offending organisms.
- One should consider MRSA in IV-drug abusers and the

immunocompromised.

Physical Exam

- Dorsal swelling is often predominant, but one should look for volar fullness and flattening of the palmar concavity.
- These infections wrap around a metacarpal and can often abduct the digits from one another.
- Other findings are similar to purulent flexor tenosynovitis.

Treatment

- Early operative intervention is paramount.
- In almost all cases, both a dorsal incision between the metacarpal heads and a volar Bruner incision is required to completely decompress the abscess.
- IV antibiotics, drains, and revision irrigation and débridements are often considered along with soap-and-water washes or Betadine soaks.

Complications

- The primary complications result from inadequate drainage or late intervention.
- Revision surgical treatment should be performed until swelling, erythema, and purulence subside.

Horseshoe Abscess

Definition

- Consists in a combined infection of the radial bursa, ulnar bursa, and the space of Parona; usually secondary to a puncture wound.

Organism

- The most common causative agent is *Staphylococcus aureus.*
- This condition commonly shares the same etiology as in flexor tenosynovitis.

Treatment

- Includes prompt surgical drainage and antibiotic coverage due to the high incidence of MRSA.
- Intravenous Ampicillin + Sulbactam or Vancomycin should be empirically used until culture results are obtained.
- Patients with diabetes or involved in IVDA should have an aminoglycoside added for gram-negative coverage.

Felon

Definition

- A felon is an abscess of the distal pulp or phalanx pad of the fingertip.

Organism

- The most common causative agent is *S. aureus.*

Treatment

- Includes incision and drainage of the affected area.
- Surgeon should avoid the fish mouth incision because it carries a high risk of vascular compromise of the digital pad.
- Antibiotic coverage for *S. aureus* should be used as well.

Complications

- The most common complications seen are osteomyelitis and distal phalanx avascular necrosis (AVN).

Paronychia

Definition

- Paronychia is an infection of the perionychium (also called eponychium), which is the epidermis bordering the nail.

Organism

- Usually *Staphylococcus aureus* or *streptococci, pseudomonas spp.*, gram-negative bacilli, and anaerobes may be present, especially in patients with exposure to oral flora.

Treatment

- Drainage is the most efficacious intervention.
- Early–try soaks and oral antibiotics (e.g., Cephalexin) can also be considered.
- Nail removal (partial or complete) is still controversial.

Chronic Paronychia

- Often seen in patients exposed to moisture over a long period of time.
- The etiology in the chronic condition may include multiple organisms such as fungi, atypical mycobacteria, and gram-negative bacteria.
- Treatment options include marsupialization (exteriorize the inflamed germinal matrix), nail removal, and antibiotics/antifungals.

Fight Bite

Description

- The most common human bite injury to the hand is clenched fist injury also known as a "fight-bite," from striking another person's mouth.
- This type of injury usually involves MCP joint.

Organisms

- Human bite infections are often more virulent than animal bite injuries and are polymicrobial in nature.
- These infections are generally caused by *Staphylococcus aureus, Streptococcus spp.,* and *Eikenella Corrodens* (causing ⅓ of cases).
- *Bacteroides spp.* remain the most common anaerobe isolated.

Treatment

- Treatment options depend on the clinical stage of the wound.
  - Noninfected wounds should be treated with irrigation, debridement, splinting, and a course of antibiotics should be strongly considered (to cover *Staphylococcus aureus, Streptococcus spp.,* and *Eikenella corrodens*).
  - Infected wounds should be treated as noninfected wounds *PLUS* intravenous antibiotics. Infected wounds should be left open.

Septic Arthritis

Natural History

- The progression of joint damage is as follows:
  - Cartilage destruction from bacterial toxins and proteolytic enzymes
  - Cartilage softening and fissuring within 7 d, impaired synovial perfusion from intra-articular pressure
  - Finally erosion of the joint capsule can occur within 3 wks.

Organism

- The causative organism can vary depending on the age and associated risk factors but *Staphylococcus aureus* and *Streptococcus* remain the most common causative agents.
- *Haemophilus influenzae* is the predominant organism in young child (most common in children <5 yrs of age) and *Gonococci* in young adult with nontraumatic monoarticular (often culture negative).

Differential Diagnosis

- Septic arthritis must be differentiated from crystalline arthropathies, although they can occur together.
- Joint aspiration is essential in the diagnosis of this condition and can help in the diagnosis of crystal arthropathies and infection (WBC > 50,000/75% PMNs/glucose < 40 mg than fasting level).

Treatment

- Incision and drainage may aid in the removal of leukocytes and destructive enzymes.

- Intravenous antibiotics should be generally organism specific and should be focused depending on the epidemiologic and clinical data of the patient.

Postoperative Rehab and Expectations

It is closely related to duration of infection and to the adequacy of treatment.

- Long-term complications generally affect the function of the joint.

Deep-Space Infections

Anatomy

- Deep-space infections generally affect the following compartments: dorsal subaponeurotic, thenar, midpalmar, Parona quadrilateral, interdigital subfascial (collar button).

Organism

- *Staphylococcus aureus* and *streptococcus* are the most common causative agents.

Etiology

- These infections are generally caused due to penetrating trauma and contiguous spread.

Treatment

- Incision and drainage remains the mainstay of therapy.
- Intravenous antibiotics should be warranted as well.

Animal Bites

Prevalence

- Animals causing bites in humans include the following: dogs, cats (appear to lead to infection more commonly –50% of cases), rodents, snakes.

Bacteriology

- These infections are multifactorial.
- *Pasteurella multocida* remains the most common isolated organism in dog and cat bites.
- *Staphylococcus* and *Streptococcus* are also common causes.
- Snake venom has proteolytic, anticoagulant, and neurotoxic effects besides the infectious organisms it has within.

Treatment

- Treatment options depend on the clinical stage of the wound.
  - Noninfected wounds should be treated with irrigation, debridement, splinting, and a course of antibiotics should be strongly considered (to cover *Pasteurella, Staphylococcus,* and *Streptococcus*).
  - Infected wounds should be treated as noninfected wounds *PLUS* intravenous antibiotics. Infected wounds should be left open.
- Dogs or cat suspected of having rabies should be observed for 10 d.
  - Human diploid cell vaccine and immune globulin should be used if there is a high index of suspicion for the animal.
  - With snakebites it is important to identify the type of snake, confirm bite, monitor hemodynamic status, and consider the use of specific antivenom.
  - Swelling may be dramatic in the affected extremity and can cause compartment syndrome.

Empiric Oral Antibiotic Therapy for Animal and Human Bites

- **Agent of choice:** Amoxicillin-clavulanate
  - Dose in adults: 875/125 mg twice daily.
  - Dose in children: 20 mg/kg per dose (amoxicillin component) two times daily (maximum 875 mg amoxicillin and 125 mg clavulanic acid per dose).
- **Alternate empiric regimens:**
  - Doxycycline, TMP-SMX, Penicillin VK, Cefuroxime, Moxifloxacin

PLUS Metronidazole or Clindamycin.

- **The following agents have poor activity against *P. multocida* and should be avoided:**
  - Cephalexin, Dicloxacillin, and Erythromycin.

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MICROSURGERY

KYLE MOYLES • ROBERT R. L. GRAY

Introduction

- Microsurgical techniques are those that require the use of high-powered microscope during the surgical procedure.
  - Microsurgery is most commonly utilized during the repair of very small blood vessels and nerves, replantation of amputated parts, and the transfer of composite tissue grafts.
  - Microsurgical techniques are used in a variety of surgical specialties including plastic surgery, hand surgery, orthopedic surgery, otolaryngology, neurosurgery, pediatric surgery, and ophthalmology.
  - Specialized instruments and a high degree of technical skill are required for the successful completion of a microsurgery procedure.
- Many microsurgical procedures, including the dissection and repair of larger caliber nerves and blood vessels, can be performed using loupe magnification of up to 5×.
  - Surgical loupes are specially designed magnification devices mounted to lenses of glasses, which are customized for each individual's vision and preferred focal length.
- For smaller diameter dissection and repair, usually for structures less than 2 mm in diameter, operating microscopes are often necessary.
  - These are large microscopes, which allow multiple individuals to view an image at 4–40× magnification.
  - The primary surgeon generally controls the position and focus of the microscope while assistants are able to view the same image

simultaneously.

- Microsurgical skills are unique and highly specialized, and like most surgical skills, require substantial practice in order to gain proficiency.
  - Because many microsurgical procedures are lengthy, excellent technique and efficiency are paramount.
  - Many hours are required to develop a baseline skill set, and regular use or practice is necessary to maintain proficiency.
- Factors causing inefficiency and fatigue for the surgeon need to be recognized and eliminated.
  - For example, appropriate posture and elbow placement are essential when performing microsurgery.
  - Even factors like caffeine consumption, which can lead to even small tremors, must be considered prior to surgery.
  - Under the microscope, even the smallest movements can have profound effects on instrument placement, which can result in surgical errors.
  - Visual spatial recognition is also an important skill to develop since the surgeon's hands are usually not within the visual field of the microscope.
- Commonly used microsurgical instruments include a microneedle holder, jeweler's forceps, and microscissors.
  - A variety of vessel clamps are also routinely used during blood vessel repair.
  - Smaller-sized nylon sutures and needles (up to 12-0) are available for use in repair and anastomoses.
  - In addition to these basic instruments, more specialized tools are available depending on the procedure being performed.

Vascular Repair

- An end-to-end microvascular anastomosis is the most common anastomosis performed, although end-to-side repairs can be performed in some instances.

- In all microvascular anastomoses, it is vital to remove any interposed adventitia, to practice careful vessel handling, and to remove any clots from the lumens.
- While a repair must be watertight, it is important that there is not too great a stenosis as this can cause a disruption in the flow and lead to clot formation.
- An anastomosis is performed first by mobilizing the proximal and distal ends in order to obtain adequate length for a tension-free repair.
  - The vessel adventitia should be removed in the vicinity of the repair; the intima walls can then be inspected and trimmed back to a normal appearance.
  - The vessel ends are then apposed and secured with a clamp.
  - Simple interrupted sutures are then placed 120 degrees apart, using the clamps to rotate the vessel in order to gain exposure to the backside of the repair.
  - Several sutures are then placed in between the original sutures to augment the repair.
  - The distal clamp is then released, followed by the proximal clamp; additional sutures can be placed if excessive leaking occurs at the repair site.
  - However, too many sutures may also cause the anastomosis to form clots at the suture line.
  - End-to-side and other techniques of beveling can be used to minimize vessel mismatch, which leads to turbulent flow and clot formation.

- Postoperatively, patients are managed by limiting caffeine, chocolate, and nicotine and warming the operated part to prevent vasospasm.
  - Numerous anticoagulant protocols are used including aspirin, heparin drip, and dextran to prevent thrombosis of the anastomoses.

Nerve Injuries

- Primary nerve repair achieves best results in patients who sustain a clean, sharp laceration, which is repaired soon after the injury.
- Depending on the size of the nerve and the orientation of its fascicles, either a epineurial or a perineurial can be performed.
- An epineurial repair is performed by mobilizing the proximal and distal ends to allow for a tension-free repair.
  - The ends are then trimmed and the fascicular structure examined in order to determine the appropriate rotational alignment of the nerve.
  - Small caliber nylon sutures are then placed in an interrupted fashion in the epineurium with attention to lining up the vessels on the surface of the nerve in order to preserve rotational alignment.
  - The repair can be augmented with a nerve-guidance conduit, which can also be used when the ends cannot be approximated without tension.
    - Currently conduit is indicated in sensory nerves only.
    - Results of conduits with mixed-motor nerves have been less satisfying.
    - Gaps in sensory nerves of up to 2–2.5 cm repaired with conduits have been shown to have at least protective sensation (two-point discrimination <11 mm).

Replantation

- Microsurgery offers surgeon the ability to replant amputated digits, hands, feet, and entire limbs.
  - While there are many considerations before undertaking a replant, important factors to consider include the age of the patient, mechanism of injury, and level of the amputation; younger patients, injuries from a sharp object, and more distal injuries tend to have better overall outcomes.
  - Depending on level of the injury, the viability of the amputated part may be up to 30 hrs if it is stored appropriately in a cold environment.

- Relative indications are injuries distal to the FDS insertion, multiple digits, thumb at any level, pediatric patients, hand, wrist, or forearm level injuries.
- Isolated flexor zone 2 level, segmental injuries, avulsion/crush injuries, and replantation in patients with multiple comorbidities, psychiatric ailments, or concomitant life-threatening injuries are relative contraindications.

- Many replantation procedures are performed with multiple surgeons and teams; the cases tend to be longer and more complex, and one team can prepare the amputated part while the other team prepares the patient.
  - Once all structures to be repaired have been thoroughly cleaned and identified, the repair can proceed.
  - The most common order of repair is fixation of bone, repair of tendons, repair of arteries, repair of nerves, and finally, repair of veins.
    - This order allows for the most stability early in the procedure.
    - The order is changed if the part has significant muscle mass that requires immediate perfusion.
  - In the immediate postoperative period, the patient should be placed on blood-thinning medication and should avoid nicotine- and caffeine-containing products.

Free Tissue Transfer

- Microsurgical techniques are also frequently used in free flaps, which are composite tissue grafts harvested from one body area and transferred to another.
- The composite tissue can include skin subcutaneous fat, muscle, nerve, bone, and other tissue.
- These free flaps are most frequently used in situations where there is need for tissue coverage in a large defect that cannot be alleviated with local tissue transfer (local flap).
- However, there are specialized uses for free flaps including vascularized bone grafts for fracture nonunions and great toe

transfer to reconstruct the thumb.

- There are many commonly described free flaps, which can be performed, and the choice of which flap is to be harvested depends on the size and location of the defect.
  - Commonly used free bone flaps include free fibular flaps, medial femoral condyle flaps, and iliac crest flaps.
  - Common muscle flaps include the latissimus, gracilis, and serratus flaps.
  - Fasciocutaneous flaps include the ALT (anterolateral thigh flap), the lateral arm flap, and the reverse radial forearm flap.

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CARPAL FRACTURES

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Scaphoid Fracture

Scaphoid Anatomy and Pathoanatomy

The scaphoid, almost entirely covered in cartilage, is in contact with the radius, as well as both the proximal and distal rows of carpal bones (lunate, capitate, trapezium, trapezoid). The main blood supply to the proximal scaphoid is from the dorsal carpal branch of the radial artery while the distal scaphoid receives its blood from the palmar carpal branch of the radial artery. However, the scaphoid is prone to avascular necrosis upon fracture because it receives its blood flow in a retrograde fashion.

Differential Diagnosis

- Physical: Tenderness at the anatomical snuff box and/or the distal pole in the volar wrist.
- History: Scaphoid fractures are some of the most common hand fractures and are generally seen when patient falls on the extended wrist (hyperextension more than 95 degrees).

Imaging

- XR: PA, lateral, and two oblique views show distal pole, proximal pole, or waist fracture.
- MRI: Most sensitive test to identify nondisplaced fractures.
- CT: Useful for determining fracture pattern and evaluating collapse.

Nonoperative Management

- Reserved only for nondisplaced fractures, multiple types of immobilization have been used.

- No significant difference has been noted in different types of casts (above vs. below elbow casts, inclusion of the thumb, or stabilization in wrist flexion vs. extension).
- Fracture healing takes on average 12–15 wks, and some patients choose surgery to limit the total time of immobilization.

Operative Management

- Numerous surgical approaches can be taken to repair a nondisplaced or minimally displaced scaphoid fractures, and the specific technique depends on the surgeon.
  - Typically, proximal pole fractures are approached dorsally, distal pole fractures are approached volarly, and waist fractures can be approached from either side.
  - In general, the surgery involves pins and/or screws to properly fix the fracture fragments, and a bone graft may be included to promote healing (see below).
- Volar percutaneous technique, dorsal percutaneous approach, and arthroscopic reduction (Geissler technique) are examples of only a few of the surgical approaches used to repair scaphoid fractures.
  - No matter the approach, a screw is positioned down the central axis of the scaphoid to maximize screw length and purchase.
  - Care must be taken to ensure that it is well buried beneath the cartilage on both ends, so usually the surgeon selects a screw that is ~4 mm shorter than the measured length of the cannulated screw's guidewire.

Postoperative Rehab and Expectations

- The goal is to regain full union of the scaphoid without any malalignment, displacement, dissociation, or nonunion, which can lead to posttraumatic arthritis (Scaphoid Nonunion Advance Collapse [SNAC]) if not fixed.
  - Osteonecrosis can occur in anywhere from 13–50% of scaphoid fractures, and the proximal pole is especially vulnerable.
  - Outcomes tend to be affected by the patient's age, how timely the

diagnosis is, and the type of treatment.

- Acute immobilization of the wrist after a scaphoid fracture has shown a union rate of up to 85–95%.
- For displaced fractures, vascularized bone grafts (when indicated) and the previously mentioned surgical approaches increase the union rate to above 95%.
- Other outcomes include improved grip strength, pinch strength, and range of motion.

Hamate Hook Fracture

Differential Diagnosis

- Physical: Deep pain on ulnar half of wrist and may be associated with dorsal dislocation of small/ring finger at the metacarpal joint.
- History: Hamate hook fractures are generally rare ($<2\%$ of carpal fractures), but are usually seen in patients with history of playing sports involving racquets or clubs, with high shear and direct pressure directly to the hook.
- Hook of Hamate pull test: While checking for pain, patient resists pull of 2 ulnar digits with wrist in ulnar deviation and hand in flexion.
  - A simpler way to visualize this is by thinking about the position of the hand when trying to pick up a grocery bag from the floor using only the two ulnar digits.

Imaging

- XR: Hamate hook fractures are easily missed on routine x-rays (AP, lateral), so multiple views are needed (oblique, carpal tunnel view).
- CT: Narrow-cut CT provides excellent visualization of the hook.

Nonoperative Management

- When diagnosed early, splint or plaster cast immobilization is occasionally effective. A fibrous nonunion is often the result, though this can be painless.

Operative Management

- Repair of the hook is challenging, especially because of its small size, and the fragment is generally excised. The sharp edge must be smoothed to prevent flexor tendon laceration.

Postoperative Rehab and Expectations

- Although fractures of the hook are rare, nonunion can result in closed rupture of the flexor tendons of the small/ring finger, requiring surgery.
  - Successful flexor tendon repair usually cannot be determined via grip strength as pre- and postoperative grip strength measurement does not improve significantly when compared to the contralateral hand.
- Most people who have undergone operative management should avoid any activity with the hand and keep it immobilized for 4–6 wks.

Pisiform Fracture

Differential Diagnosis

Physical: Point tenderness over volar ulnar side of wrist, just distal to the wrist flexion crease.

History: Pisiform fractures are rare, but can be a result of a hyperextended wrist with a direct blow to the hypothenar eminence.

Imaging

- XR: Radiography is essential, but pisiform fractures are easily missed on routine x-rays.
- Thus, multiple views or CT scans are needed with suspicion of a pisiform fracture.

Nonoperative Management

- Immobilization via cast or splint, with wrist closed in palmar flexion and ulnar deviation.

Operative Management

- The pisiform can be excised if fracture leads to disabling symptoms (pisotriquetral arthritis).

Postoperative Rehab and Expectations

- Nonunion of the pisiform or pisotriquetral arthritis can result from pisiform fractures.
- Complications of pisiform excision are rare, but include tendon or ulnar nerve damage.
- While nonunion of the pisiform does occur, it is rare. Furthermore, pisiform fractures usually heal with 3–6 wks of immobilization.

Scaphoid Nonunion

Incidence

- Scaphoid nonunions typically present months after a patient had suffered a scaphoid fracture, either because of improper healing or because the fracture may have gone unrecognized (misinterpreted as a sprain, for example).
- Treating scaphoid fractures early is crucial, because nonunion rates rapidly increase if left untreated.

Pertinent Anatomy

- See above.

Imaging

- Diagnosis is usually made with via XR, showing the improper healing at the site of a scaphoid fracture.
- An MRI can help determine the blood supply to the bone and any avascular necrosis.
- CT scans are used to evaluate the position of the fragments and identify collapse.

Operative Treatment

- Nonunions are initially treated with operative fixation with or without the use of some type of bone graft.
- Bone graft can restore the anatomy of the scaphoid and promote

fracture healing.

- If arthritis is detected, management focuses on salvage procedures such as proximal row carpectomy, four-corner fusion, or total wrist arthrodesis.

Graft Options

- Bone graft can be from various places, including the iliac crest.
- Vascularized grafts improve the viability of the proximal pole and can come from the distal radius or 1st or 2nd metacarpals on a pedicle, or taken as free grafts from the medial femoral condyle or iliac crest.
- Grafting is contraindicated in patients with radiocarpal and midcarpal arthritis, or in patients with damage to the radial artery.

Postoperative Rehab and Expectations

- Prognosis seems to be linked to risk factors such as heavy laborers, short period of postoperative immobilization, previous surgery, avascular necrosis, and chronic nonunions.
- There is a decreased success rate of union of the scaphoid if the duration of nonunion is longer than 5 yrs.
- Sclerosis in the proximal pole is indicative of avascular necrosis, mostly due to its highly limited blood supply. In general, 5–10% of all scaphoid fractures lead to nonunion.

Other Carpal Fractures

Differential Diagnosis

- Most of these fractures are rare and require specialized imaging techniques because they are so easily missed. Thus, taking a proper physical and history are essential.
- Most occur secondary to force applied along other parts of the hand (indirect force to index metacarpal, for example, can lead to a trapezoid fracture).
- Fractures of the triquetrum are common in children, especially skaters.

Nonoperative Treatment

- Most are treated nonoperatively, immobilizing the bone to promote carpal stability.
- Closed reduction usually has positive outcomes if performed early.

Operative Management

- For some of these fractures, open reduction (with K wires) and internal fixation can be performed if closed reduction fails.
- Capitate fractures need to be evaluated to check for avascularity, which is an indication for surgery.
- Fifth carpometacarpal fracture dislocation is a relative indication for hamate surgery.

Postoperative Rehab and Expectations

- The goal is to restore carpal stability and is generally successful if treated early.
- Nonoperative management has excellent outcomes; however, when bones have subluxed or present indications for surgery, open reduction and internal fixation have shown to be equally successful.

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ARTHRITIC CONDITIONS OF THE HAND AND WRIST

AMAR ARUN PATEL • ROBERT R. L. GRAY

Osteoarthritis

Pathoanatomy

- Commonly affects DIP joint of the digits and CMC joint of the thumb
- MCP joint is usually minimally involved

Differential Diagnosis

- Presents with pain, limited ROM, and swelling.
- Patients are often less symptomatic than radiographs may suggest.

Imaging

- Classical radiographic findings are joint space narrowing, osteophyte formation, and subchondral cysts/sclerosis.

Treatment

- Initial treatment is always supportive with activity modification, NSAIDs, and corticosteroid injections.
- Refractory cases may be amenable to operative treatment.

DIP Joint Arthritis

Pathoanatomy

- Most common location due to highest joint reaction forces.

- Osteoarthritic changes are known as Heberden nodes (secondary to marginal osteophytes) and mucous cysts with or without nail deformities are common.
- Mucous cysts that do not resolve should be excised and the osteophyte should be removed.
- Cyst recurrence is not uncommon unless the joint is fused.
- Erosive changes are more common in the DIP joint and occur in middle-aged women.

Operative Management

- Operative intervention involves arthrodesis with headless screws (10% nonunion) or K-wires, or a tension band technique.
- Joint should be fused in 5–10° of flexion.
- Arthroplasty is also available, but results are less predictable and it is rarely employed.

PIP Joint Arthritis

Pathoanatomy

- Less common than DIP arthritis.
- Osteoarthritic changes are known as Bouchard nodes (secondary to marginal osteophytes).
- Operative intervention involves arthrodesis or arthroplasty.
- Arthrodesis is associated with more predictable outcomes.

Operative Management

- Fusion angles in flexion (index 40°, long 45°, ring 50°, small 55°) to recreate normal cascade.
  - Headless screws, K-wires, and a tension band technique can be employed.
- Arthroplasty is indicated for long and ring fingers (used in power grip) with good bone stock and no deformity.
  - Arthroplasties may be compromised due to the lateral stresses

associated with pinch and are rarely used in the index.

- Unlinked surface replacement arthroplasty is gaining favor, but has a higher complication rate than linked silicone prostheses.

MCP Joint Arthritis

Pathoanatomy

- Mostly secondary to rheumatoid disease or hemochromatosis; rarely seen in primary cases.

Treatment

- Arthroplasty is preferred treatment (acceptable results have been seen in linked silicone and in unlinked surface replacement arthroplasties).
- Arthrodesis limits ROM, but may be needed for failed arthroplasty or septic arthritis.
- Fusion angles in flexion (index 25°, long 30°, ring 35°, small 40°, thumb 10–20°).

CMC (Trapeziometacarpal) Joint Arthritis

Pathoanatomy

- Most common joint affected after DIP arthritis.
- Occurs due to attenuation of the anterior oblique (Beak) ligament leading to instability and dorsoradial subluxation.

Differential Diagnosis

- CMC grind test (axial compression and circumduction) elicits pain, and late findings are metacarpal adduction
- MCP hyperextension during pinch, and first webspace contractures.
- Roberts view (pronated thumb AP) is the recommended radiographic view.

Classification

- Eaton and Littler Classification:
  - Stage I (prearthritis with joint space widening secondary to synovitis)
  - Stage II (joint narrowing, osteophytes < 2 mm)
  - Stage III (marked narrowing, osteophytes > 2 mm)
  - Stage IV (pantrapezial with STT involvement)

Nonoperative Treatment

- Nonoperative treatment with thumb spica orthosis and steroid injections.

Operative Treatment

- Refractory cases require operative treatment.
- There are many different surgical options with most involving complete trapeziectomy, though some only require partial excision of the trapezium.
- Other options can augment treatment:
  - Ligament reconstruction and tendon interposition (LRTI, most common, FCR or APL tendon used for interposition)
  - Suspensionplasty (Weilby and Thompson most common)
  - Hematoma distraction (pinning of 1st into 2nd metacarpal to maintain trapeziectomy space with pin removal at 6 wks).
- Implant arthroplasties have significantly higher complication rates compared with other methods.
- For early stages, ligament reconstruction, arthroscopy, and debridement have been advocated.
- Young laborers have better pain relief and stability from joint arthrodesis (35° radial abduction, 30° palmar abduction, 15° pronation).

Wrist Arthritis

Pathoanatomy

- Most commonly posttraumatic arthritis.
- Scapholunate advance collapse (SLAC) wrist most common followed by scaphoidtrapezio-trapezoid (STT) arthrosis and scaphoid nonunion advance collapse (SNAC) wrist.
- Chronic distal radioulnar joint (DRUJ) instability may lead to arthritic changes.

Nonoperative Treatment

- Nonoperative treatment includes NSAIDs, bracing, and steroid injections.

Operative Treatment

- Chronic DRUJ arthrosis may be treated with
  - distal ulna resection (Darrach procedure)
  - partial resection, ulnar head replacement (long-term results unclear)
  - Suavé–Kapandji procedure (DRUJ fusion with proximal pseudoarthrosis, good for manual laborers).

Miscellaneous Topics

Rheumatoid Arthritis

Pathoanatomy

- Systemic autoimmune inflammatory disease affects the synovial joint space.
- Usually spares DIP joints, unlike osteoarthritis.
- Presentation in the hand is associated with aggressive disease patterns.
- Clinically associated with
  - ulnar drift at the MCP joint (radial hood stretches allowing extensor tendons to drift)
  - Boutonnière deformity (central slip rupture)
  - swan neck deformity (volar plate laxity), chronic DRUJ instability,

and tendon rupture (caput-ulna syndrome and Mannerfelt lesion).

Nonoperative Treatment

- Treatment consists of immunomodulating medication (DMARDs), NSAIDs, and splinting.

Operative Management

- Operative treatment includes synovectomy, tendon reconstruction, and joint fusion/arthroplasty.

Psoriatic Arthritis

Pathoanatomy

- Seronegative spondyloarthropathy affecting 20% of patients with psoriasis.
- HLA B27 positive in 50% of patients.
- Manifests with
  - dactylitis (“sausage digits”)
  - onychodystrophy (“nail pitting”)
  - DIP “pencil-in-cup” deformity
  - MCP extension with PIP flexion.

Differential Diagnosis

- Associated findings include silvery plaque rash and uveitis.

Treatment

- Treatment consists of supportive measures with immunomodulators.
- Surgical options include joint fusion and resection arthroplasty in refractory cases.

Systemic Lupus Erythematous

Pathoanatomy

- Affects primarily young women and presents with rheumatoid-like presentations in the upper extremity.
- Deformities include ulnar deviation and volar subluxation of the MCP joint, ligamentous laxity, and joint swelling.

- Other symptoms include malar rash, Raynaud phenomenon.
- Immunologic markers are anti-DNA and antinuclear antibodies.

Treatment

- Immunomodulators are mainstay, and arthrodesis is surgical treatment of choice.

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CALCANEUS FRACTURES

MATTHEW SIMONS • ALAN LEAGUE

Calcaneus Anatomy

The calcaneus has three articular facets (anterior, middle, and posterior) on the superolateral aspect that articulate with the talus. The posterior facet is the major weightbearing surface, articulating with the talar body, and the flexor hallucis longus tendon runs just inferior. The sustentaculum tali is a medial projection that forms the "constant" fragment in calcaneal fractures due to its connection to the talocalcaneal and interosseous ligaments. Intra-articular fractures are particularly problematic because the calcaneus supports 3 times body weight during normal gait and is in direct contact with the ground. This relationship predisposes fracture fragments to loss of reduction and malunion if the patient bears weight prematurely.

Clinical History

- Calcaneus fractures typically occur by axial loading or shearing forces during a fall from a height or MVA.
- They represent 2% of all fractures in adults and are five times more common in men than women.
- Ten percent of patients will have lumbar spine fractures and 26% associated lower extremity fractures.
- Seven to 17% are open fractures.

Differential Diagnosis

- Due to the typical axial loading, the possibility of additional lower extremity fractures should be closely evaluated, including the midfoot, talus, ankle, leg, knee, and hip.

Physical Exam

- Patients. present with a swollen, tender hindfoot, ecchymosis, and possible tarsal tunnel nerve dysfunction.
- The heel is typically shortened, widened, and in varus.
- Fracture blisters are common and may appear anywhere in the foot, proportional to fracture displacement and swelling.
- Higher-energy injuries result in more severe soft tissue disruption, with open injuries frequently affecting the medial aspect of the foot and heel.
- Care should be taken to assess whether severe pain is due to the fracture itself and not due to compartment syndrome of the foot, especially the deep, or calcaneal compartment.

Imaging

- XR:
  - AP and lateral as well as Harris axial XRs usually show a short, widened calcaneus, with varus orientation and medial displacement of the tuberosity.
  - Bohler and Gissane angle may be measured on the lateral film.
    - Normal Bohler angle is between 25 and 40 degrees but is decreased with facet depression.
    - A normal Gissane angle is between 95 and 105 degrees and increases with complete facet depression.
    - Both Bohler and Gissane angle may be normal when only the lateral half of the posterior facet is displaced, and on the lateral may appear as a so-called “double density” sign.
- CT: will further assess posterior facet comminution and fracture into the calcaneocuboid joint.

Classification and Fracture Patterns

- Sanders is based on coronal CT to assess intra-articular fractures involving the posterior facet and carries prognostic value.
  - Type I: Nondisplaced
  - Type II: Two-part, displaced
  - Type III: Three-part with posterior facet depression
  - Type IV: Severely comminuted
- Intra-articular fractures typically start at Gissane angle and form an anteromedial fragment and a posterolateral fragment.
  - The anteromedial fragment consists of the anterior and middle facets, the sustentaculum tali, and a part of the posterior facet, considered the "constant fragment" as it remains connected to the talus and medial malleolus.
  - The posterolateral fragment holds the tuberosity, lateral wall, and a part of the posterior facet, pulled into varus by the Achilles tendon.
- Extra-articular fractures involve the anterior or medial processes, tuberosity (including tongue-type), sustentaculum, or body.

Prevention

- For those who work at heights, proper harnessing and suspension equipment are essential.

Nonoperative Management

- Type I fractures with an intact Achilles can be treated with 10–12 wks of immobilization and non-weightbearing.
- Other nondisplaced or minimally displaced fractures, anterior process fractures with $<25\%$ articular involvement, and red flag patients (vasculopaths, diabetics, elderly), should be considered for non-op treatment.
- This is especially true of smokers as they are prone to wound and

fracture healing complication if treated operatively.

- Use a bulky Jones dressing and begin active subtalar motion once swelling subsides.

Operative Indications

- Types II–IV, anterior process fractures (>25% involvement), displaced tuberosity, and fracture-dislocations are treated operatively.
- Surgery decreases the likelihood that a patient will later require a subtalar fusion.
- Surgical fixation must be done after the resolution of edema (skin wrinkle sign), approximately 1–2 wks after injury.
- ORIF for intra-articular fractures with large fragments.
  - With more comminution, ORIF is reasonable but is associated with greater chance of subtalar arthritis.
- Primary subtalar fusion should be considered in more highly comminuted injuries (Sanders IV).

Surgical Technique

- **Displaced-tongue fractures:** Best treated by percutaneous pin fixation, using a large posterior reduction clamp for reduction.
- **Goals of open reduction:** Joint restoration; calcaneus height, length, and heel-width restitution.
  - Lateral, extensile approach is most popular, but a medial approach, or combined approaches are also acceptable.
  - No-touch retraction is used, with a pin placed in the tuberosity fragment or inferior talus to assist reduction.
  - The lateral calcaneal wall is visualized, and all soft tissues, particularly the sural nerve and peroneal tendons, are protected.
- **Gross reduction:** Mobilization of the tuberosity is usually necessary to access the posterior facet and anterior process.

- To do this, a Schanz pin is inserted and pulled distally with a valgus moment applied. This maneuver produces a grossly aligned heel.
- **Anterior process reconstruction:** Reduction of the entire calcaneus proceeds from anterior to posterior and from medial to lateral.
  - The anterior process is typically reconstructed first and is secured to the stable medial fragment.
  - Successful anatomic reconstruction of the anterior process is critical because this determines the relationship between the anterior, middle, and posterior facets and contributes to the lateral column length.
  - Articular reduction using the "constant fragment" is key to maintaining an anatomic relationship to the talus.
  - Multiple heel views should be obtained from a range of 10–50 degrees to confirm accurate placement of the sustentacular screw.
- **Posterior facet:** When reconstruction of the anterior process is complete, the posterior facet is reconstructed and placed into anatomic position.
  - If multiple posterior facet fragments are present, reduction continues from medial to lateral.
  - Varus deformity must be corrected.
  - The medial wall reduction may be indirectly assessed by fluoroscopy and the posterior facet under direct visualization.
- **Plate fixation:** Provisional K-wires are replaced by definitive plate and screw fixation.
  - Bone auto- or allograft can be used to fill the defect, usually below the crucial angle of Gissane.
  - For most fractures, an 8- or 9-hole 2.7-mm reconstruction plate is used, although a Letournel Y plate may be used for tongue types.
  - Other implant options include cervical H plates, T plates, mini 2-mm plates, and ¼ tubular plates.
  - Closure is done in two layers over a drain, and the ankle splinted in neutral.

Complications

- Infections and wound breakdown are the most devastating complications.
  - Wound infections, classified as early wound sloughs or late deep infections occur in 2–15% of fractures treated surgically.
  - Soft tissue breakdown is most common at the apex of the incision.
  - Wound problems may be minimized by keeping hardware away from the corner of the incision.
- The complexity of the calcaneus and subtalar joint make hardware complications somewhat frequent (~20%).
  - Proud screws or plunging drills may penetrate the flexor hallucis longus medially.
  - Inappropriate lateral incisions can injure the sural nerve and result in cutaneous neuroma.
  - A more inferior lateral-L approach makes this problem less likely.
  - Anterior ankle impingement following malreduction after the talus settles and lateral impingement of the fibula on the peroneals have been described.
- Posttraumatic subtalar osteoarthritis results from initial damage to articular surface and may occur in spite of anatomic reduction.
  - Bohler angle has significant prognostic value in terms of predicting morbidity, whereby diminished initial values show a much poorer 2-yr outcome regardless of treatment.
  - Three percent of patients treated surgically, and 17% treated non-surgically may later require subtalar arthrodesis.

Postoperative Rehab and Expectations

- Rehabilitation begins immediately after surgery, with passive range of motion (ROM) for the toes.
- ROM for the ankle and subtalar begins after the wound drainage stops, typically 48 hrs after surgery.

- ROM exercises should continue to 12 wks, until the patient is walking. Hip, quadriceps and gluteal muscle strengthening can begin during this time to prevent muscle atrophy.
- However, it is crucial that patients remain non-weightbearing for a minimum of 12 wks.
- At 12 wks, patients advance gradually from toe touch to full weightbearing in 20–25 lb increments, progressing as XR evidence of bone healing allows.

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TALUS FRACTURES

MATTHEW SIMONS • ALAN LEAGUE

Talus Anatomy

There are no tendon attachments to the talus and 60–70% of its surface is articular cartilage. Stability is imparted by the bony anatomy, joint capsules, ligaments, and synovial tissues. The superior body is widest anteriorly and fits more rigidly in the ankle mortise in dorsiflexion. The extraosseous blood supply comes from three main arteries: posterior tibial, anterior tibial, and perforating peroneals. The artery of the tarsal canal (branch of the posterior tibial) and the artery of the tarsal sinus (from the perforating peroneal) form an anastomosis inferiorly that branches into the talar neck. The artery of the tarsal canal is the main blood supply to the talar body. Importantly, the deltoid branch of posterior tibial artery supplies the medial portion of talar body. The head and neck are predominantly supplied by the dorsalis pedis and perforators via the artery of the tarsal sinus. Because of extensive intraosseous anastomoses, preservation of at least one extraosseous blood supply in severe injuries can adequately maintain bony circulation.

Clinical History

- Talar neck fractures account for 50% of fractures.
- The mechanism is commonly from MVA/motorcycle trauma and falls from a height, resulting from forced dorsiflexion ("aviator's astragalus") into the anterior lip of the tibia, with an axial load.
- Low levels of force result in nondisplaced neck fractures while higher energy ruptures the posterior talocalcaneal and interosseous ligaments, leading to subluxation or dislocation of the subtalar

joint.

- The calcaneus typically dislocates anteriorly and medially with the remainder of the foot.
- Associated ipsilateral injuries are frequent, with 10% having an associated fracture of the calcaneus and 20–30% of the medial malleolus.
- Extrusion of the talar body can also occur.
- Lateral process talus fractures, frequently seen in snowboarders, occur after an uncontrolled axial load during a hard landing, with the ankle dorsiflexed, inverted, and externally rotated.

Physical Exam

- Following trauma, there will be acute pain, difficulty or inability to bear weight, swelling of the hindfoot and midfoot, and localized tenderness.
- Neurovascular structures are generally spared but soft tissue damage may be extensive and occasionally these are open fractures (50% of type III).
- A talus fracture may be only part of the patient's total injuries; thus a complete trauma survey is essential.

Imaging

- AP, lateral, and oblique XRs of the foot and ankle are standard.
  - Canale view (maximum equinus, 15 degrees pronation and 75 degrees cephalad from horizontal) gives the best view of the talar neck.
- CT and MRI are frequently necessary to delineate the fracture and assist in surgical planning.
- Postoperatively, assess for Hawkins sign (subchondral lucency in the talar dome, best seen on mortise view at 6–8 wks) to evaluate for revascularization.
  - Absence of Hawkins sign indicates avascular necrosis.

Classification and Fracture Patterns

- The Hawkins classification describes talar neck fractures based on neck displacement and congruency of the subtalar and ankle joints.
  - Higher grades involve greater trauma and portend a poorer prognosis.
    - Type I: Nondisplaced (0–15% AVN)
    - Type II: Subtalar subluxation or dislocation (20–50% AVN)
    - Type III: Subtalar and tibiotalar dislocation (70–100% AVN)
    - Type IV: Subtalar, tibiotalar, and talonavicular dislocation (70–100% AVN)
- Other fracture types include that of the head, body, posterior process, or lateral process (snowboarder's fracture).

Nonoperative Management

- Type I fractures are treated with short-leg cast immobilization and non–weightbearing for 6–8 wks.
  - Patients are protected an additional 2 wks in a walking cast.
- Nondisplaced talar body, lateral process, and impaction-type head fractures are immobilized and kept NWB in an SLC until fracture healing, typically 6 wks.

Operative Indications

- All displaced talar neck fractures (types II–IV) and head, body, lateral, and posterior process fractures are treated with ORIF.
- Type III fractures frequently represent a surgical urgency to relieve skin tension and to address kinking of the only remaining blood supply from branches within the deltoid ligament.

Surgical Technique

- Approach:
  - Talar neck fractures are approached with the patient supine, through a combined anteromedial and/or anterolateral technique.
  - The anteromedial approach is made from the anterior aspect of the medial malleolus to the dorsal aspect of the navicular tuberosity.
  - Exposure may be extended with a medial malleolar osteotomy if necessary to gain exposure to the body.
  - To visualize the reduction and remove debris from the subtalar joint, an anterolateral incision is made from the tip of the fibula to the anterior process of the calcaneus.
  - Fractures of the posterior body are performed prone through a posteromedial or posterolateral approach.
  - Lateral process fractures are approached laterally.
- Displaced neck fractures (II–IV):
  - Reduction proceeds from the medial side and any varus, dorsiflexion, or malrotation of the neck must be corrected.
  - For types III and IV, a femoral distractor or external fixator can distract the calcaneus to help extricate the body fragment.
  - Reduction and subtalar joint congruity are assessed from the lateral side.
  - Open fractures are potentially devastating injuries and meticulous I&D must be performed.
  - Extrusion of the body fragment carries high morbidity, but revascularization and survival of fragment may be achieved with aggressive debridement and reinsertion.
- Fixation:
  - K-wires are placed retrograde across the fracture sight.
  - Cannulated or solid screw can be placed for definitive fixation.
  - Countersink screws if they are placed near or through the talonavicular joint.
  - If there is extensive comminution medially, a small plate (2.0–2.7 mm) may be used for fixation of the lateral wall where cortical bone is stronger.

    - Screws placed from posterior to anterior provide increased strength compared to those placed through the talar head; however, this requires a third incision (using the interval between flexor hallucis longus and the peroneals) and its importance is debatable.
    - type IV, consideration should be given to pinning the talonavicular joint.
    - Titanium screws have the advantage of MRI compatibility to allow early assessment of AVN.
- Displaced talar body:
    - A medial malleolar osteotomy is generally necessary for adequate visualization and provides attention to the deltoid pedicle for improved vascularity.
    - Talar dome fragments are reduced from posterior to anterior and from lateral to medial.

Complications

- Skin necrosis requires early debridement and either skin grafting or free muscle transfer to minimize the risk of osteomyelitis.
- With extruded talar body fragments that are grossly contaminated, most authors support discarding such pieces to minimize the risk of sequestrum.
- Nonunion is less common than varus malunion in the talar neck.
- Malunion in type II is 0–25%, and in types III–IV between 18% and 27%.
- Varus malunion leads to decreased subtalar eversion and weightbearing on the lateral border of the foot.
- A triple arthrodesis or medial opening wedge osteotomy of the talar neck is frequently necessary to treat the difficult problem of varus malunion.
- Avascular necrosis is classically evaluated on a mortise XR at 6–8 wks following injury.
- Hawkins reported that subchondral lucency (osteopenia) is an active

process that rules out the possibility of AVN.

- Subtalal (50%) and ankle joint arthritis (33%) and arthrofibrosis are common, with increasing rates in higher fracture types.

Postoperative Rehab & Expectations

- With stable fixation, early range of motion may begin once the wounds are healed. Injuries with more severe comminution or instability should be immobilized until provisional healing between 4 and & 6 wks.
- Weightbearing is advanced once there is XR evidence of fracture union, which may take 2–3 mos.

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TARSAL AND METATARSAL FRACTURES

LESLIE SCHWINDEL • ALAN LEAGUE

Tarsal Fractures

Injuries to the Transverse Tarsal (Chopart) Joint

Anatomy

Chopart joint (transverse tarsal joint) = calcaneocuboid + talonavicular joints. Allows hindfoot to pivot while forefoot remains stationary. Together with the subtalar joint, forms a unit to invert and evert the foot.

Mechanism

- Inversion
- Medial displacement of forefoot
- Force applied to metatarsal heads of plantarflexed foot
- Eversion
- Abduction force on forefoot.

Classification

- Main and Jowett identified five patterns of injury based on:
  - the direction of the applied force
  - the consequent direction of deformity
  - the presumed mechanism
  - the extent of injury: medial, longitudinal, lateral, plantar, and crush.

Treatment

- Nondisplaced = walking SLC × 4 wks → post-op shoe until pain-free.
- Displaced: reduce → stable: immobilize, treat non-op (usually not stable though).
- Unstable: stabilize with k-wires or external fixator.
- Post-op: SLC NWB × 6 wks → protected PWB in walking cast/boot if screws used.
  - If k-wires: remove at 6 wks and NWB additional 4–6 wks.
  - After this initial period, patient allowed to ambulate in good shoe with longitudinal arch support for additional 9–12 mo.

Navicular, Cuboid, & Cuneiform Fractures

Anatomy

Navicular largely covered with articular cartilage; surface area available for nutrient vessels is limited; more susceptible to osteonecrosis than other bones of the midfoot. Cuboid is important stabilizer of lateral column.

Mechanism

- Forceful inversion-PF
  - Eversion
  - Acute eversion or valgus injury to the foot
  - Fall from a height or MVA with proximally directed forces on a plantar-flexed foot.
- Cuboid: indirect force whereby foot placed in forced abduction with foot plantar flexed.
  - Cuboid stress fractures have been described in athletes
- Cuneiform:
  - Direct injuries are the most common
  - Indirect violence involves force being transmitted proximally up the metatarsals, across the tarsometatarsal joint, and into the cuneiform.

Classification

- DeLee has broadly classified navicular fractures into four groups:
  1. Avulsion fractures of the dorsal lip
  2. Fractures of the tuberosity
  3. Displaced and nondisplaced fractures of the body
  4. Stress fractures.

Treatment

- Nondisplaced fxs, most avulsion fxs: SLC 4–6wks.
- Navicular/cuboid stress fxs: NWB SLC × 6–8wks.
- Displaced: ORIF.
- Post-op: NWB SLC × 6–8wks → progress WB.

FOREFOOT INJURIES

First Metatarsal + MTP Joint Injuries

Anatomy

First MTP joint stability provided by joint congruence and the surrounding ligaments.

Mechanism

- Forced hyperextension of MTP beyond normal range of dorsiflexion leads to sprain (“turf toe”).
- Fractures/dislocations result from stubbing of the toe/axial loading or direct blow from falling object.

Presentation

- Frank dislocation of first MTP joint almost always dorsal in direction.

Treatment

- Nondisplaced: post-op shoe × 2–3wks.
- Displaced: CRPP vs. ORPP.

Sesamoid Fractures

- Avulsion, overuse, or direct trauma.
- The medial (tibial) sesamoid is more commonly injured. Treat in SLC or stiff-soled shoe until tenderness subsides and there is some radiographic evidence of healing (usually by 6 wks).

Metatarsal Shaft Fractures

Anatomy

Metatarsals connected distally by deep transverse metatarsal ligaments; limits displacement of isolated MT shaft fxs. Force of intrinsic/extrinsic flexors tends to produce plantar displacement/angulation of MT neck fxs.

Mechanism

- Direct blow to the foot, most commonly affecting the second, third, and fourth metatarsals.
- Stress fractures of the shaft result from repetitive stresses, which cumulatively lead to fatigue fractures of the bone.
- Fractures of the metatarsal heads usually result from a direct blow to the foot, and multiple metatarsals are frequently involved.

Treatment

- Metatarsal stress fxs: activity restriction × 3–4 wks.
- Non/minimally displaced: walking SLC × 3 wks → WBAT in a well-padded shoe.
- Displaced: closed reduce → stable: walking SLC w/ toe plate.
- Unstable: CRPP vs. ORPP (allowing displaced fractures to persist will disrupt the normal weightbearing across the forefoot).

Phalangeal Fractures

- Closed reduction with buddy taping × 2–3 wks, post-op shoe.
- Dislocations of PIP/DIP of lesser toes uncommon, but can be reduced and typically remain stable; buddy tape × 2 wks.

Proximal 5th Metatarsal Fractures

Anatomy

Three zones: Zone 1 = most proximal, includes tuberosity and its insertion of peroneus brevis; zone 2 = more distal, includes region where interosseous ligaments connect fourth/fifth MT; zone 3 = just distal to zone 2, extends into diaphysis for approximately 1.5 cm. Nutrient artery enters medially in middle ⅓ of bone and gives off short proximal/distal branches. Watershed area between this blood supply and that of the small metaphyseal vessels at each end.

Mechanism

- Zone 1: Avulsion fractures from peroneus brevis tendon or plantar fascia
- Zone 2: Adduction force on a plantar-flexed foot
- Zone 3: Stress fractures in athletes/runners, or inversion injury.

Classification

- Classified by location of fracture: zone 1, 2, or 3 (see above).

Treatment

- Zone ⅓ fracture OR
- Zone 2 fracture in low-activity patient → short-leg cast and/or metatarsal functional bracing
- Zone 2 fractures → NWB in cast for 6 wks, or intramedullary screw fixation

Imaging

- AP, lateral, oblique views of foot +/− 3 views of ankle
- Special views:
  1. Talar neck (special oblique view of the talar neck described by Canale and Kelly)
  2. Lisfranc = 30-degree oblique view of foot (>2 mm widening between medial cuneiform & second MT base indicative of injury) ("fleck sign" = fleck of bone between first/second MT bases; avulsion fracture of Lisfranc ligament)
  3. Sesamoid = tangential view.

- Weightbearing films when possible. If not, can manually stress (i.e., Lisfranc injury); comparison views often helpful
- CT can be used to better visualize fracture patterns; they are NWB so not helpful in determining stability
- If dx still unclear → MRI (can evaluate soft tissues) (i.e., Lisfranc ligament)
- If stress fracture suspected, may not appear on plain XR; radionuclide bone scan, or MRI more sensitive
- Important to r/o things like accessory navicular, bipartite sesamoid

Postoperative Rehab and Expectations

- Nonoperative: missed injury, deformity, post-traumatic arthritis.
- Operative: skin/wound-healing problems, neurovascular injury, CRPS, prominent/symptomatic hardware, hardware failure.
- Regardless of treatment: osteonecrosis, nonunion/malunion, skin necrosis/infection, compartment syndrome.

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LISFRANC INJURIES (TARSOMETATARSAL FRACTURE–DISLOCATION)

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Lisfranc Anatomy and Pathoanatomy

The Lisfranc joint is comprised of 9 bones (5 metatarsals, 3 cuneiforms, and the cuboid bone) and represents the division between the midfoot and forefoot. The stability of the Lisfranc joint is created through a combination of osseous and ligamentous support. The bony architecture creates an arch called the "transverse" or "roman" arch and contains a recessed articulation at the second metatarsal called the keystone. This creates an intrinsically stable structure with little motion at the medial and middle columns of the foot, while allowing for some motion in the lateral column.

Classification

- Although multiple classifications exist, none are particularly useful in determining treatment or prognosis.

Clinical History

- Injuries can be designated as indirect or direct.
- Indirect injuries are the result of a force applied along the longitudinal axis of the foot during plantar flexion.
- The injury may be the result of low or high energy mechanism such

as a fall from height, athletic injury, or MVA.

Physical Exam

- Patients often present with inability to bear weight, forefoot and midfoot edema, and ecchymosis along the plantar arch.
- Dorsalis pedis pulse should also be examined since significant dislocations can compromise blood flow.

Imaging

- Weightbearing AP/Lateral/Oblique radiographs should be obtained.
- **AP:**
  - The first intermetatarsal space should be contiguous with the space between the medial and middle cuneiforms. Diastasis >2 mm is pathologic.
  - A line drawn from medial border of the second metatarsal should correspond to the medial border of the middle cuneiform.
  - Fleck sign: seen in first metatarsal space and represents an avulsion of the Lisfranc ligament from the base of the second metatarsal. This is diagnostic for a Lisfranc injury.
- **Lateral:**
  - Dorsal and plantar aspects of the MTs should correspond with the cuneiform and cuboid.
  - Oblique (30-degree internal rotation)
  - Medial border of the fourth MT should line up with the medial border of the cuboid.
- **MRI:**
  - May perform if x-rays are equivocal. If there is edema with no identifiable ligament tear or subluxation, then perform CT scan to identify subluxation.

Nonoperative Management

- No displacement seen on weightbearing or stress radiographs.
- May also be considered for nonambulatory patients, significant vascular disease, or severe peripheral neuropathy.
- Patients should be immobilized for 8 wks.

Operative Management

- Any disturbance in normal radiographic parameters.

Surgical Technique

- Timing
  - Await for soft tissue swelling to resolve prior to proceeding.
  - Most injuries should be managed within 2 wks; however, up to 6 wks may be acceptable.
  - Open injuries, irreducible dislocations, or compartment syndrome should be managed emergently.
- Considerations:
  - Fluoroscopy
  - Radiolucent table
  - Small and mini fragment set (2–4 mm screws)
  - Reduction clamps
  - K-wires
  - Dental pick
  - Small battery powered drill
  - Tourniquet
- Positioning:
  - Supine, foot positioned at the end of the table
- ORIF:

- Single or dual longitudinal incisions are made between the first and second rays.
- Exposure of the first TMT joint is made between the long and short hallux extensor tendons.
- Instability of the intercuneiforms should be reduced first, followed by fixation of the first through third TMT joints using transarticular screws, and K-wire fixation for the and fifth TMT joints.
  - ORIF Post-op care:
    - Patients should be placed in a short leg cast and remain non-weightbearing for the first 6 wks.
    - Patients are then transitioned into a cam boot and advanced to full weightbearing by 8–10 wks.

- Arthrodesis:
  - May be considered for purely ligamentous injuries or chronic injuries that have led to arthrosis.
  - Articular segments should be denuded of cartilage and fused using cortical screws.
    - Arthrodesis post-op care:
      - Patients should remain non-weightbearing in a cast for 6 wks. Patients are advanced to partial weightbearing in a cam boot during wks 8–12, and full weightbearing in a shoe at 3 mo.

Postoperative Rehab and Expectations

- Physical therapy may be initiated after full weightbearing to help with gait and balance.

Complications

- Post-traumatic arthritis and may lead to long-term disability and an alteration in gait.
- Treatment includes arthrodesis.

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ANKLE INSTABILITY

MATTHEW SIMONS • ALAN LEAGUE

Anatomy and Biomechanics

The important lateral ankle ligaments include the anterior talofibular ligament (ATFL), calcaneofibular ligament (CFL), and posterior talofibular ligament (PTFL). The ATFL is the most important lateral stabilizer, working as a restraint to supination and anterior translation, as well as limiting plantar flexion and internal rotation. It originates 1 cm proximal to the tip of the fibula at the anterior-inferior border of the fibula and inserts on the anterior aspect of the lateral malleolar facet of the talar neck, on average 18 mm proximal to the subtalar joint. The ligament is contiguous with the joint capsule, rather than a distinct structure and may be hard to define after chronic sprains. The CFL originates adjacent to the ATFL, approximately 8 mm from the tip of the fibula and inserts on the lateral tubercle of the calcaneus. The CFL is deep to the peroneal tendons and contiguous with the joint capsule, but is easily identified. The origins of the ATFL and CFL are occasionally avulsed together from the fibula, forming a fragment of bone from trauma called an “os subfibulare.” The PTFL runs from the digital fossa on the posterior aspect of the fibula to the lateral tubercle of the talus. Disruption starts with the anterolateral joint capsule and progresses to the ATFL and CFL, depending on injury severity.

Clinical History

- Ankle sprain injuries are the most common injury sustained during sports.
  - They represent up to 40% of all musculoskeletal injuries and are most commonly seen in athletes participating in basketball,

soccer, running, ballet, and gymnastics.

- The majority are lateral ankle sprains, typically the result of excessive inversion and internal rotation of the hindfoot while the leg is in external rotation.
- The majority of acute ankle sprains do well with the "RICE" regimen and rarely require surgery.
- Lateral ankle instability refers to the presence of an unstable ankle due to an injury to the lateral ligaments.
- The hallmarks of chronic ankle instability are persistent pain, recurrent sprains, and repeated instances of the ankle giving way.
- Other causes of chronic ankle pain that may be confused or associated with instability include osteochondral lesions of the talus and longitudinal peroneal tendon tears.

Physical Exam

- For suspected chronic ankle instability, standing mechanical alignment should be inspected to note existing hindfoot varus.
- Hindfoot motion should be assessed and peroneal muscle strength tested.
  - Note any signs of generalized ligamentous laxity with Beighton hypermobility score.
- Proprioception is tested with a modified Romberg test, and patients with grade III ankle sprains have up to 86% and 83% of peroneal nerve and tibial nerve stretch injury, respectively.
- The two most common provocative tests for lateral stability are the anterior drawer and talar tilt.
  - With the knee flexed, anterior drawer evaluates the ATFL by holding the calcaneus in one hand, stabilizing the distal tibia with the other, and translating the calcaneus forward with the ankle in 10–15 degrees of plantar flexion.
  - Increased translation of 3 mm compared to the uninjured side or an absolute value of 10 mm suggests ATFL deficiency.
  - When translation is increased in both plantar flexion and

dorsiflexion, both the ATFL and CFL are deficient.

- Laxity of the CFL is assessed with the talar tilt test, described as the angle between the talar dome and the tibial plafond during forced hindfoot inversion with the talocrural joint held in neutral.
- The normal range of tilt varies from 5–23 degrees; however, 10 degrees of absolute talar tilt or 5 degrees difference compared to the contralateral side is generally considered a test.

Classification

- Classification systems have generally been applied to acute lateral ankle injuries but may be useful to assess chronic ankle laxity.
  - Grade I: ATFL stretched (mild swelling and tenderness; minimal difficulty with ROM and WB)
  - Grade II: ATFL torn ± partial CFL tear (moderate swelling, ecchymosis; anterolateral ankle tenderness, restricted ROM, increasing pain with WB)
  - Grade III: ATFL and CFL torn ± capsular tear ± PTFL tear (diffuse swelling, ecchymosis; tenderness over anterolateral capsule, ATFL, CFL; inability to bear weight)

Imaging

- XR:
  - Standard views include lateral and mortise of the ankle.
  - Note any anterior tibial osteophytes or talar exostoses or osteochondral lesions.
  - AP and lateral stress views (knee flexed, ankle slightly plantar flexed) may help quantify and/or confirm the clinical diagnosis of instability.
  - Both ankles should be stressed for comparison.
- MRI:
  - As the physical exam warrants, MRI is performed without contrast

to evaluate for associated pathology, particularly the assessment of a peroneal tendon tears or osteochondral lesion.

Conservative Treatment Nonoperative Management?

- A well-designed rehabilitation program is first-line treatment and should focus on proprioception, strength (particularly peroneal strength), and motion deficits.
- There is support that ankle-foot orthoses, stiff-soled shoes, and lateral heel wedges may prevent or minimize the recurrence of instability.
- Functional ankle bracing or taping is frequently successful in preventing recurrent sprains.
- Ankle pain alone, without symptoms of instability, is usually not an indication to reconstruct an unstable ankle.

Operative Indications

- The degree of disability appreciated by the patient is one of the most important considerations and can be significant in both the low- and high-demand individual.
- Classic indications for surgery are persistent, symptomatic instability, unresponsive to a functional rehabilitation program after 6 mo from the index injury or symptoms.

Surgical Techniques

- Several techniques are described that involve either of two basic categories: anatomic ligament repair or augmented ligament reconstruction.
- The most accepted techniques are described below.
- **Anatomic ligament repair:**
  - Broström technique:

    - Foundation of the anatomic repair that imbricates the ATFL and CFL midsubstance and sutures the ruptured ligament ends.
  - Gould modification:
    - Augments the Broström repair by mobilizing and reefing the lateral extensor retinaculum and attaching it to the fibula after imbrication of the ATFL and CFL.
  - Karlsson modification:
    - Involves shortening the ATFL and CFL (because they are believed to be elongated and scarred, not ruptured) and reattaching to their anatomic origins through drill holes.
    - This technique uses a Kessler stitch to oversew the proximal ends to the distal ends to reinforce the repair.
- **Augmented ligament reconstruction:**
  - Watson–Jones:
    - Original nonanatomic tenodesis; routs the peroneus brevis tendon from posterior to anterior through the fibula.
    - The graft is routed through the neck of the talus and sutured back onto itself.
    - The ATFL may be anatomically restored if the bone tunnels are located properly.
  - Evans:
    - Tenodesis of the peroneus brevis to the fibula either by directly suturing the tendon to periosteum or securing it to the posterior fibula through a bone tunnel.
  - Chrisman–Snook:
    - Uses a split peroneus brevis tendon routed from anterior to posterior through the fibula down into the calcaneus through bone tunnels.
- **Role of Arthroscopy**
  - Several intra-articular pathologies are associated with chronic instability that may be treated with arthroscopy including talar osteochondral lesions, impingement, loose bodies, symptomatic ossicles, adhesions, chondromalacia, and osteophytes.

- These conditions may independently cause ankle pain and, if left untreated, may compromise the results of a ligament stabilization procedure.

Complications

- Pain and instability: Most common cause of chronic pain is a missed injury, including injuries to
  - the anterior process of calcaneus
  - lateral or posterior process of the talus
  - base of the fifth metatarsal
  - peroneal tendon
  - syndesmosis
  - osteochondral lesion
  - tarsal coalition
  - impingement syndromes.

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ANKLE ARTHROSCOPY AND OCD LESIONS OF ANKLE

LESLIE SCHWINDEL • ALAN LEAGUE

Osteochondral Defects of The Ankle

Osteochondral defects of the ankle are focal articular cartilage injuries with underlying bony involvement in the form of edema, fracture, and/or cyst formation. They most commonly involve the talus and are often associated with a single traumatic event to and/or chronic instability of the ankle (repetitive microtrauma). The talus is the third most common location for OCDs behind the knee and elbow. Mechanisms of injury include inversion with the foot in dorsiflexion (lateral OCD) and an inversion-external rotation injury with the foot in plantar flexion (posteromedial OCD). Talar OCDs are usually posteromedial or anterolateral. A singular significant traumatic event is more often associated with a deep medial lesion, whereas recurrent instability is more closely related to a wafer-like lateral lesion.

Anatomy and Pathoanatomy

The talus articulates with the tibia (tibial plafond and medial malleolus) and fibula (lateral malleolus) to form the ankle joint. The talus is broader anteriorly and has no muscular or tendinous attachments. Much of its blood supply is received through its neck via branches of the dorsalis pedis (artery of the tarsal canal), posterior tibial, and peroneal arteries (artery of the tarsal sinus). Blood supply to the talar dome is, therefore, retrograde, giving it an intrinsic difficulty healing OCDs. OCD lesions are comprised of both hyaline articular cartilage and its underlying subchondral bone. In traumatic lesions, rotational and compressive forces crush the subchondral bone and crush/shear the cartilage.

Clinical History

- Patients with an OCD lesion of the talus typically present after a traumatic injury to the ankle.
- The incidence of OCDs of the talar dome in patients with acute lateral ankle ligament ruptures is 4–7% ("chondral injury" reported in up to 50% of acute ankle sprains).
- Patients typically complain of pain, stiffness, swelling, instability, and/or catching/locking of the ankle.
- Severe mechanical symptoms such as catching and grinding may indicate a severe OLT and possibly a loose body.
- Chronic ankle pain and stiffness without improvement from conservative measures should increase the suspicion for OCD.

Physical Exam

- Ligamentous laxity can be a predisposing factor by allowing the talus to be subjected to abnormal stresses during repeated subluxation events.
- The ankle should be tested for abnormal anterior drawer and talar tilt to evaluate the ATFL and the CF ligaments, respectively.
- Patients with lateral lesions are generally tender over the anterolateral joint line with the ankle in plantarflexion while patients with medial lesions are tender over the posteromedial joint line with the ankle in dorsiflexion.
- Effusions may often be present.
- Often, however, exam may be remarkably normal.

Imaging

- Weight-bearing x-rays of the ankle (AP, lateral, mortise) → can be used to detect bony defects in the talar dome; however, it will fail to recognize a purely cartilaginous injury and underlying bone edema.

  - If present, should see an area of detached bone surrounded by radiolucency. Heel rise mortise view may help reveal a posterior defect.

- MRI:
  - Most sensitive diagnostic test for OCDs.
  - There is low intensity signal on T1 images when sclerosis is present in a chronic OCD.
  - A fluid rim of high intensity underneath the OCD on a T2 image suggests an unstable fragment.
  - MRI findings have been shown to correlate closely with visual findings on arthroscopy.
- CT:
  - Frequently helpful in documenting the precise size and location and can be helpful for operative planning.

Classification

- Classification systems are based mainly on radiographic imaging.
- Classifications exist based on plain x-ray findings as well as CT, MRI, and intra-operative arthroscopy findings.
- The most classically referred to system is that of Berndt and Harty, though MRI is the usual modality used to identify the lesion.
- The Berndt and Harty classification is based upon plain radiography.
- Loomer later added a stage V to this system:
  - Stage I: Subchondral compression (fracture)
  - Stage II: Partial detachment of osteochondral fragment
  - Stage III: Completely detached fragment without displacement from fracture bed
  - Stage IV: Detached and displaced fragment
  - Stage V: Subchondral cyst present

Nonoperative Management

- Conservative treatment usually consists of immobilization and reduced or non-weightbearing for approximately 6 wks, followed by progressive weightbearing and physical therapy.
- This protocol is instituted for Berndt and Harty type I and II lesions and small grade III lesions.
- Success rates for nonoperative treatment have been poor, with some authors reporting only a 45% success rate with nonoperative treatment.
- No distinct, optimal time period for nonoperative treatment has been determined, but most surgeons recommend a trial of 4–6 mo before proceeding to surgery, for asymptomatic or low symptomatic patients.

Operative Indications/Options

- Large grade III and any grade IV lesions are generally considered operative candidates.
- In addition, grade I and II lesions that fail nonsurgical management are also operative candidates.
- Goals of operative treatment are to restore the surface anatomy of the talar dome, thereby normalizing joint reactive forces and preventing the progression of arthrosis.
  - The three categories of operative treatment are:
    1. primary repair of the OCD
    2. stimulation of fibrocartilage healing to fill the defect
    3. transplantation of osteochondral tissue to fill the defect.
  - OCDs can be assessed/treated by ankle arthroscopy or by open arthrotomy with/without medial malleolar osteotomy.
    - Arthroscopy becoming more popular due to the decreased morbidity, decreased healing time with faster rehabilitation, and earlier resumption of sports, among other things.
    - Anterior arthroscopy used in most cases, and can access most

OCDs, but occasionally an open arthrotomy with medial malleolar osteotomy or a two-portal posterior approach is indicated based on lesion location.

  - Recent meta-analyses have shown a lack of evidence regarding the most effective surgical treatment for OCD lesions of the talus in adults.

- **Primary repair:**
  - Large OCD lesions (>15 mm) with healthy-appearing surface cartilage attached to a bone fragment fixation with: headless screws
  - K-wires - for temporary fixation
  - Absorbable pins (usually acute injuries; this technique typically fails in chronic injuries)
- **Bone marrow stimulation:**
  - Most common treatment for lesions <15 mm in diameter include:
    1. Retrograde drilling (lesions with intact articular cartilage)
    2. Microfracture → objective is to remove all unstable cartilage and underlying necrotic bone and then to stimulate healing of the defect.
  - Awls/drills used to perforate the base of the lesion 3–4 mm apart; brings mesenchymal stem cells, growth factors, and cytokines to the defect.
  - The fibrin clot heals in the defect and eventually becomes fibrocartilage (type I cartilage), which fills the void but lacks the organized structure of hyaline cartilage (type II cartilage).
  - Fibrocartilage possesses inferior wear characteristics to hyaline cartilage.
- **Cartilage restoration:**
  1. Osteochondral autograft or allograft transplantation (OATS)
  2. Autologous chondrocyte implantation (ACI)
  3. OATS plugs are cylinders of articular cartilage/bone harvested from the same patient, typically from the non-weightbearing portion of the knee.

- They are placed into the freshly debrided OCD lesion with a press-fit technique.
- Have been used in patients with highly cystic lesions, or secondarily after failed index procedure; advocated in larger defects.

4. ACI utilizes cultured autologous chondrocytes implanted underneath a periosteal or synthetic patch to stimulate the growth of hyaline-like cartilage. Can be cultured/transplanted on collagen matrix, but not approved by FDA.
   - ACI only restores chondral surface, not well-suited for deep lesions.
   - Disadvantage of ACI is that two procedures are required; however, OATS requires two operative sites.
   - Both have advantage over bone marrow stimulating techniques in that transplantation of hyaline or hyaline-like cartilage is involved.

Surgical Technique

- Ankle arthroscopy (anterior) → many indications, including treatment of OCD lesions.
  - Anterior and posterior approaches described; anterior most common.
  - Contraindications: infection, severe degenerative changes.
  - The role of diagnostic ankle arthroscopy without a pre-op diagnosis is limited; only 26–43% of patients benefit from procedure, compared with upward of 75–80% success after arthroscopic treatment of OCD lesions.
- Positioning:
  - Supine with bump under ipsilateral buttock.
  - Tourniquet is placed around the upper thigh and the heel of the foot rests on the very end of the table.
  - Routine fixed distraction versus plantarflexion to open joint: controversial & typically surgeon preference.

- Surgical technique:
  - Two primary portals used for anterior arthroscopy:
    1. anteromedial
    2. anterolateral
  - Accessory anterior portals and a posterolateral portal may be used as well, if indicated.
  - Anteromedial portal made first, just medial to tibialis anterior tendon over the joint line.
  - When using a distraction device, a smaller scope is often used, such as a 2.7 mm scope.
    - Once the scope is introduced, saline is introduced into the joint and the anterolateral portal established under direct visualization using a spinal needle.
    - It is placed lateral to the peroneus tertius tendon, taking care to avoid the superficial peroneal nerve.
    - After establishing both portals, joints are assessed, OCD localized, and pathology addressed via one or more of the above techniques.

Complications

- Reported rate of complication varies widely in the literature, but is thought to be low.
- This includes neurovascular injury, iatrogenic articular surface injury, synovial fistula, infection, CRPS. The superficial peroneal nerve is at highest risk, and injury to this nerve is associated with the anterolateral portal.
- Of reported complications, nearly 50% are neurologic.

Postoperative Rehab and Expectations

- Postoperative protocols vary, but generally include an initial period of non-weightbearing for 4–6 wks.

    - Active plantarflexion and dorsiflexion is encouraged after wounds have healed.
    - Most authors encourage progression of weightbearing by 6 wks, with formal physical therapy if needed to work on range of motion and strengthening.
    - Running activities are typically avoided for at least 12 wks, and cutting/jumping sports for 4–6 mo.
- Recent studies have shown that the intermediate-term results of arthroscopic treatment of OCD lesions of the talus are maintained over time.
    - Proposed prognostic factors include defect size, patient age, BMI, history of trauma, and duration of symptoms.
    - Thus far, only size of the defect has shown any association with clinical outcome. No long-term studies on outcomes after microfracture, and no level 1 studies comparing the various surgical techniques.
    - Some studies report 85% success rate of microfracture in the short-to-intermediate term.

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PTT DYSFUNCTION/ADULT ACQUIRED FLAT FOOT DISORDER

MICHAEL MERZ • ALAN LEAGUE

Posterior Tibial Tendon Anatomy and Function

The posterior tibial tendon (PTT) has its origin in the deep posterior compartment of the leg on the tibia, interosseous membrane, and fibula. It is the anteromedial most structure running in a groove on the posterior aspect of the medial malleolus. The tendon then divides into 3 parts: the anterior aspect inserts into the navicular and medial cuneiform; the middle inserts into the second & fifth metatarsals, middle and lateral cuneiforms, and the cuboid; the posterior part inserts on the sustentaculum tali. The tendon is innervated by the tibial nerve and receives its blood supply from the posterior tibial artery. It acts as an invertor of the foot and plantarflexor of the ankle in addition to helping create a rigid midfoot for toe-off during gait.

Adult Acquired Flat Foot Disorder

- PTT dysfunction is the primary cause of adult acquired flat foot disorder (AAFD) as it is the primary dynamic support of the arch.
- The PTT is generally affected 2–6 cm proximal to the navicular, which is a watershed region.
- Dysfunction of the calcaneo-navicular or spring ligament also contributes to the adult acquired flat foot.
- It is important to determine if the flat foot is flexible or rigid, as that will guide treatment.

Clinical History

- The greatest incidence of AAFD is during fifth–seventh decades and it is more common in women. Initially, patients present with medial pain and swelling over the PTT.
- Deformity proceeds, with lateral and dorsal subluxation of the foot around the talus.
- The hindfoot deforms into a valgus position, which can cause impingement and lateral ankle pain.
- Patients will also have abduction of the forefoot and can develop Achilles tendon contractures.

Physical Exam

- Patients with advanced disease have collapse of their medial arch, hindfoot valgus, abduction of the forefoot, and contracture of their Achilles.
  - The following exams are helpful in making the diagnosis:
    - Single leg heel rise:
      - Examine patient from behind while they stand on one foot and raise their heel off the ground with their knee straight.
      - The hindfoot should return to neutral or varus in a normal exam.
      - Failure to lift heel and tilt into varus indicates PTT dysfunction.
    - Too many toes sign:
      - Examine a standing patient from behind.
      - If you can see more toes on the effected foot than the unaffected foot then the test is positive.

Imaging

- Weightbearing
  - AP, lateral, and oblique radiographs should be obtained.

- The most reliable and reproducible ways of measuring flat foot on radiographs are using:
  - Calcaneal Pitch:
    - On lateral x-ray the intersection of a line along inferior border of calcaneus and line from inferior most aspect of calcaneus to the inferior most part of fifth metatarsal head.
    - Normal: 18–20 degrees
  - Talometatarsal (Meary) Angle:
    - On lateral x-ray, intersection of line through mid-axis of talus and line through mid-axis of first metatarsal.
    - Flatfoot when less than -4 degrees
  - Talonavicular Coverage Angle:
    - On AP x-ray, intersection of line through the articular surface of talus and line through the articular surface of the navicular.
    - Normal is <7 degrees
- A standing AP x-ray of the ankle can evaluate competence of the deltoid ligament, which is lax in Stage IV.
- MRI is not necessary for diagnosis but can offer additional information not readily apparent on physical exam or weightbearing x-rays such as:
  - severity of PTT injury
  - spring ligament injury
  - sinus tarsi syndrome
  - plantar fasciitis
  - deltoid ligament failure.

Classification

- Classification of PTT dysfunction as a cause of AAFD helps guide treatment options.
- Stage I: PTT synovitis and pain but no deformity of AAFD and able

to perform single toe heel rise.

- Stage II: Flexible flatfoot deformity, difficult or unable to perform single leg heel rise
  a. < 40% talonavicular uncoverage
  b. > 40% talonavicular uncoverage
  c. Fixed forefoot supination and varus
- Stage III: Rigid flatfoot deformity, unable to perform single toe heel rise, possible subtalar arthrosis.
- Stage IV: Rigid flatfoot deformity, ankle valgus, ankle arthritis.

Nonoperative Management

- There is evidence supporting the various types of nonoperative management.
- Most would advocate for a trial of nonoperative treatment prior to surgical intervention.
- Some methods are physical therapy, bracing, orthotics, anti-inflammatory medicines, rest with either a removable boot or short leg cast for 1–3 mo.
- Corticosteroid injection is controversial due to the risk of PPT rupture.

Operative Indications

- For all stages of PTT disease, operative treatment is indicated if pain persists despite appropriate conservative treatment.

Surgical Technique

- Surgical treatment goals are to decrease symptoms, increase function of the patient and restore the foot and ankle to a normal position.
  - Always assess for gastrocnemius or Achilles contracture as recession or lengthening may also be indicated.

- Stage I:
  - Tenosynovectomy, tendon repair, or tendon transfer
  - Controversial to include medializing calcaneal osteotomy
- Stage II:
  - Tendon transfer of FDL to the navicular to augment for the PTT dysfunction
    a. Medializing calcaneal osteotomy
    b. Lateral column lengthening through distal calcaneus +/− medializing calcaneal osteotomy if additional correction needed
    c. If navicular is aligned with first tarsometatarsal joint, dorsal open wedge (Cotton) osteotomy of the medial cuneiform.
      - If navicular not aligned, then fuse the first tarsometatarsal joint and/or navicular–cuneiform joint.
      - In addition, the procedures listed for Stage IIa or b should be performed based on the percentage of talonavicular uncoverage.

Stage III:

  - Triple arthrodesis of subtalar, talonavicular, and calcaneocuboid joints or less frequently selective fusion of only 1 or 2 hindfoot joints.
- Stage IV:
  - Literature is limited but general consensus is that when tibiotalar arthritis is present and lateral tilt not correctable a pantalar arthrodesis should be performed.
  - If tibiotalar joint space preserved and lateral tilt passively correctable, deltoid reconstruction can be attempted in addition to triple arthrodesis.

Postoperative Rehab and Expectations

- All procedures involving osteotomy, arthrodesis, or tendon transfer are followed by a period of non- or toe-touch weightbearing generally from 6–10 wks, then followed by progression of weightbearing, stretching, and strengthening.

- Patients who are treated with triple arthrodesis should be followed for development of tibiotalar or midfoot arthritis.
- Pain is usually resolved and patient returns to low-impact activities 6–12 mo postoperatively.

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HALLUX VALGUS

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Anatomy and Pathoanatomy

Exact etiology is undetermined; however, it is likely multifactorial with both intrinsic and extrinsic factors. Intrinsic factors include genetic predisposition, ligamentous laxity, and structural deformities such as pes planus and convex metatarsal head. Extrinsic factors include high heels and narrow toed shoes.

Clinical Evaluation

- Assess whether the patient's concern relates to cosmesis or difficulty with shoe wear, or pain and transfer metatarsalgia.
- The patient's occupation and involvement in athletics should also be evaluated prior to making any surgical decisions.

Physical Exam

- Assess overall alignment of the lower extremity, the hallux, and its relationship to the lesser toes while standing.
- Determine ROM of the hallux during plantar and dorsiflexion and look for instability.
- Evaluate the second MTP for any deformity.
  - This joint is often involved and symptomatic.

Imaging

- Should be weightbearing to assess the severity of the deformity.
  - Hallux valgus angle: is determined by measuring the angle between the long axes of the proximal phalanx and the first metatarsal. Normal is <15 degrees.
  - Intermetatarsal angle: represents the angle between the first & second metatarsals. Normal is <9 degrees.
  - Distal Metatarsal Articular Angle (DMA): represents the angle between the distal articular surface and long axis of the first metatarsal. Normal is <10 degrees.
- **Decision Making**
  - Determine degree of deformity, presence of arthrosis, and whether or not the MTP joint is congruent (proximal phalanx parallel to the metatarsal head).
  - Severity of deformity will determine nature of procedure.
    - Mild: HVA <30 degrees, IM <13 degrees
      - Tx: Chevron distal metatarsal osteotomy
    - Moderate: HVA <40 degrees, IM >13 degrees
      - Tx: proximal osteotomy, or Lapidus TMT arthrodesis
    - Severe: HVA >40 degrees, IM >20 degrees
      - Tx: proximal osteotomy or Lapidus TMT arthrodesis

Nonoperative Management

- Initial treatment should include a shoe with a wide toe box. Patients that continue to remain dissatisfied or symptomatic may consider surgery.

Operative Management

- Akin Procedure (proximal phalangeal osteotomy)
  - Indications
    - Congruent joint large medial eminence, DMA <10 degrees.

  - Used largely to treat hallux valgus interphalangeus, or aid in reduction when combined with additional procedures.
  - This procedure is never used in isolation to treat hallux valgus.
- Chevron Procedure
  - Indications: mild deformity, HVA <30 degrees, IM <13 degrees
  - Contraindications: HVA >35 degrees, IM >15 degrees
  - Complications: incomplete correction, over correction, stiffness, AVN
  - Technical aspects: combine medial closing wedge osteotomy if DMA is >10 degrees
- Distal Soft Tissue Procedure Plus Proximal Metatarsal Osteotomy (Proximal Crescentic Osteotomy)
  - Indications: HVA >30 degrees, IMA >13 degrees
  - Contraindications: arthrosis
  - Complications: hallux varus, recurrence of hallux valgus, dorsiflexion of metatarsal osteotomy, nonunion or dorsiflexed malunion at osteotomy site
- Lapidus procedure (first tarsometatarsal arthrodesis with distal soft tissue procedure
  - Indications: HVA >30 degrees, IMA >13 degrees
  - Contraindications: inability to remain non-weightbearing
  - Complications: over correction, under correction, nonunion
- Juvenile Hallux Valgus
  - Delay surgery until skeletal maturity unless patient is symptomatic.
  - Treatment is based on degree of deformity as outlined above.
  - Avoid operating through physis to prevent growth disturbance.

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LESSER TOES DYSFUNCTION

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Introduction

The lesser toes are the second to fifth toes. Their deformities can be considered flexible or rigid depending on whether or not they are passively correctable. Deformities are caused by an imbalance between intrinsic and extrinsic muscle forces on the toes.

- The intrinsic muscles (Flexor Digitorum Brevis (FDB), lumbricals, and interossei) have a net effect of flexion of the metatarsophalangeal joint (MTPJ) and extension of the proximal interphalangeal joint (PIPJ) and distal interphalangeal joint (DIPJ).
- The extrinsic muscles (extensor digitorum longus (EDL), extensor digitorum brevis (EDB), and flexor digitorum longus (FDL)) have a net effect of extension of the MTPJ and flexion of the PIPJ and DIPJ. There are multiple causes leading to an imbalance such as neuromuscular, congenital, inflammatory arthropathy, trauma and, most significantly, inappropriate shoe wear.
- Lesser toe deformities, particularly of the second toe, can also be caused by deformities of the hallux, such as hallux valgus.

Lesser Toe Deformities

Hammer Toe

Anatomy and Pathoanatomy

It is primarily a flexion deformity of the PIPJ with hyperextension of DIPJ most common and neutral position or extension of the MTPJ and can be caused by an overactive EDL. It is the most common deformity of the lesser toes and can frequently be seen with other deformities, particularly MTPJ instability. On physical exam calluses are found on the dorsum of the PIPJ.

Physical Exam

- The "Push Up" test is a physical exam maneuver where dorsal pressure is applied to the metatarsal head of the affected toe.
- If the deformity corrects with the push up test then it is flexible.

Nonoperative Treatment

- Conservative treatment consists of padding for the dorsal PIPJ in addition to shoe accommodation with high and wide toe box.

Surgical Technique

- Surgical treatment for flexible deformity typically consists of FDL tendon transfer to the extensors.
- Surgical treatment of rigid deformities necessitates resection arthroplasty or arthrodesis of the PIPJ with or without FDL tenotomy.

Claw Toe (Intrinsic Minus Toe)

Anatomy and Pathoanatomy

Primary deformity is extension of MTPJ with hyperflexion of PIPJ and DIPJ. Similar to claw hand it is caused by a weakness of the intrinsic muscles. Condition is often bilateral and in multiple toes particularly when in conjunction with neuromuscular disease such as Charcot–Marie–Tooth. Commonly associated with metatarsalgia and depression of the metatarsal head leading to plantar keratosis as well as callus on the dorsal surface of the PIPJ.

Nonoperative Treatment

- Conservative treatment consists of padding for the dorsal PIPJ and a plantar metatarsal pad in addition to shoe accommodation with high and wide toe box.

Surgical Technique

- Flexible deformity is treated surgically with FDL to EDL tendon transfer, EDL and EDB tendon lengthening, and MTPJ capsular release.

- Rigid deformities are treated further with resection arthroplasty or arthrodesis of the PIPJ with or without a Weil osteotomy of the metatarsal.

Mallet Toe

Anatomy and Pathoanatomy

Isolated flexion deformity of the DIPJ with the MTPJ and PIPJ in neutral position. Caused by contracture of the FDL or rupture of the EDL at the DIP. Calluses form on the dorsum of the DIPJ as well as the tip of the toe.

Nonoperative Treatment

- Conservative treatment consists of relieving pressure on the tip of the toe, which is often the most painful part with padding and increased toe box height with a low heel.
- For flexible deformities, surgical treatment consists of FDL tenotomy or tendon transfer to dorsum of phalanx, which prevents cock-up deformity.
- Rigid deformity necessitates treatment with resection arthroplasty or arthrodesis of DIPJ.

Curly Toe

Anatomy and Pathoanatomy

Flexion deformity of PIPJ and DIPJ with the MTPJ in neutral or flexion often with a rotational aspect. This deformity is usually bilateral, congenital, and occurring in the fifth toe. It is caused by contractures of the FDL & FDB.

Nonoperative Treatment

- Conservative treatment is usually adequate, but if it becomes painful or deforming to the nail, tenotomy or tendon lengthening is performed on the flexor tendons of the toe.

MTP Instability & Crossover Toe

Anatomy and Pathoanatomy

Most often occurs in the second toe followed by the third. A drawer test of the MTPJ in the dorsal–plantar plane elicits pain and subluxation of the joint. Instability can also be in the medial–lateral plane, which most often leads to a crossover toe and is typically concomitant with hallux valgus. Crossover toe also has a PIPJ flexion contracture and is differentiated from hammer toe by also having an axial plane deformity. These conditions are associated with insufficiency or disruption of the plantar plate and capsule. Evaluation with a musculoskeletal ultrasound can confirm diagnosis and also rule out a Morton neuroma.

Nonoperative Treatment

- Conservative treatment consists of buddy tapping or stapping toe into neutral position.
- A metatarsal pad can also help relieve plantar MTP pain.

Surgical Technique

- Surgical treatment for mild cases consists of flexor to extensor tendon transfers with release of medial collateral ligament for medial crossover toe.
- More severe cases are treated with Weil osteotomies of the distal metatarsal with or without repair of the plantar plate.
- Surgical correction of crossover toe should coincide with surgical treatment of hallux valgus when present.

Bunionette (Tailor's Bunion)

Anatomy and Pathoanatomy

Defined as a lateral prominence of the distal aspect of the fifth metatarsal head.

Classification

- Classification is based on the weightbearing AP x-ray of the foot.

Nonoperative Treatment

- Conservative treatment for all types consists of more accommodative shoe wear and padding of the prominence.

Surgical Technique

- Surgical treatment is not commonly needed.
- Type I
  - enlarged fifth metatarsal head and normal alignment.
  - Surgical treatment is lateral condylectomy.
- Type II
  - is a lateral bowing of the fifth metatarsal diaphysis.
  - surgical treatment is distal Chevron osteotomy.
- Type III
  - lateral bowing of the fifth metatarsal with a widened fourth and fifth intermetatarsal angle (>8 degrees).
  - Surgical treatment is oblique diaphyseal rotational osteotomy.

Freiberg Disease

Anatomy and Pathoanatomy

Also known as Freiberg infraction and generally affects the dorsal aspect of the second metatarsal head. Disease is due to recurrent microtrauma or avascular necrosis, which ultimately leads to subchondral collapse. Patients present with localized pain worse with weightbearing.

Nonsurgical Treatment

- Initially consists of offloading the metatarsal head with stiff sole or metatarsal bar and protected weightbearing.

Surgical Technique

- Surgical treatment is on a spectrum with regard to
  - the severity of the disease from debridement of the joint through a dorsal incision,
  - dorsal closed wedge metaphyseal osteotomy (to reorient the preserved plantar cartilage into the joint space),
  - Finally partial head resection.

Interdigital Neuroma (Morton Neuroma)

Anatomy and Pathoanatomy

Poorly understood neuropathy of the common digital nerve most commonly in the third interspace between the third and fourth metatarsals. Believed to be due to increased thickness leading to compression in a narrow interspace and repetitive trauma ultimately leading to neuroma formation. On exam, pain localized to plantar surface of affected interspace with a majority of patients experiencing pain radiating to affected toes. Symptoms are worse with activity and tight shoes.

Differential Diagnosis

- Diagnosis is made with history and physical exam, and can be confirmed with musculoskeletal ultrasound.
- Mulder sign is helpful for by applying mediolateral (squeezing) pressure to metatarsals, which reproduces the patient's pain, while also palpating the distal/plantar interspace for a click.

Nonoperative Treatment

- Modification of shoes for a larger toe-box and use of a metatarsal pad is the best conservative treatment.
- Metatarsal pad should be placed 2–3 cm proximal to site of pain.

Surgical Technique

- Surgical treatment consists of common digital nerve transection, including its branches, 3 cm proximal to transverse metatarsal ligament allowing for retraction of the stump and reduced rates of stump neuroma.

Soft Tissue Disorders

Corns

Anatomy and Pathoanatomy

Hyperkeratotic lesions due to external pressure on the toes that are generally subdivided into "hard" and "soft" types. Hard corns are found most commonly on the dorsal or lateral aspect of the 5^{th} toe and due to a prominent condyle. Soft corns are macerated lesions occurring most commonly between the 4th and 5th toes and are also due to prominent condyles.

Nonoperative Treatment

- Conservative treatment for both conditions consists of more accommodative shoe wear and padding of the corns.
- Hard corns can be shaved with removal of the seed of the corn.
- For recalcitrant cases, bony prominences can be excised

Plantar Keratosis

Anatomy and Pathoanatomy

Hyperkeratotic tissue on the plantar surface of the foot due to increased pressure underneath the metatarsal head. Discrete type is localized and most often due to prominent tibial sesamoid or fibular condyle. Diffuse type is due to pressure from the entire metatarsal head.

Nonoperative Treatment

- Conservative treatment for both types consists of padding and callus shaving.

Surgical Technique

- Surgical treatment consists of excising the offending bony prominence or a shortening or dorsiflexion osteotomy of the metatarsal.

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FOOT & ANKLE ARTHRITIS/OSTEONECROSIS

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Arthritis and Osteonecrosis of The Foot & Ankle

Symptomatic Osteoarthritis

Symptomatic osteoarthritis (OA) of the ankle occurs nine times less frequently than at the knee/hip, even though the ankle experiences greater pressure per unit of surface area and is the most commonly injured joint in the body. Other locations of arthritis in the foot & ankle include the midfoot and forefoot. Most common is that of the first metatarsophalangeal (MTP) joint (hallux rigidus). Arthritis in the foot and ankle is predominantly post-traumatic secondary arthritis. Primary, idiopathic OA with no apparent initiating factor comprises only 10% of patients with ankle arthritis. In contrast, >70% of patients have some history of trauma, including fracture/dislocations, ligament injury with chronic instability, or osteochondral injury. Other causes of secondary arthritis include inflammatory disorders, gout, and neuropathic degeneration.

Osteonecrosis

Osteonecrosis, also called avascular necrosis, most commonly involves the talus. It may also include areas such as the navicular (Kohler disease, Muller–Weiss disease), the metatarsals (second: Freiberg disease), and the sesamoids. Trauma is the most common cause of osteonecrosis, particularly talar neck fractures. Alternative causes include corticosteroid use, alcohol abuse, and medical diseases such as Gaucher's, sickle cell anemia, hemophilia, hyperuricemia, lymphoma, and hemodialysis use.

Anatomy/Pathophysiology

The ankle joint consists of a highly constrained articulation of the talus with the tibial plafond and the distal fibula. With weightbearing, congruity between the sulcus of the talus and the tibial plafond provides stability in the sagittal plane. Injured ligaments around the ankle destabilizes this highly congruent joint and can lead to sagittal/coronal imbalance. With time, damage occurs to articular cartilage and subchondral bone, producing inflammation, osteophytes, progressive loss of motion, and functional disability. Similarly, arthritis of the midfoot and forefoot are most commonly due to trauma. Lisfranc injuries specifically are at high risk for this.

- Proposed mechanisms of primary OA of the ankle and midfoot include intrinsic malalignment (i.e., hindfoot varus/valgus) as well as structural abnormalities from advanced adult flatfoot. Some studies suggest that larger tibial and talar radii are present in primary OA patients, leading to a flatter joint surface and less stability, depth, and containment. The etiology of hallux rigidus is unclear. Trauma is believed to be the main cause in patients with unilateral presentation. Other proposed etiologies: Achilles tendon tightness, poor shoe wear, or elevated first ray (metatarsus primus elevatus).
- Osteonecrosis refers to cellular death within bone caused by a lack of circulation. This is the result of a mechanical disruption of the vessels or from occlusion of either arterial inflow or venous outflow. Trauma is the most common means of disruption, but other possible sources of vascular occlusion include thrombosis, embolism, corticosteroid use, alcohol abuse, and various medical conditions previously described.

Clinical History/Physical Exam

- Patients with arthritis/osteonecrosis of the ankle often complain of joint pain, tenderness, swelling, or locking.
  - Patients with midfoot involvement may present with pain on loading of the midtarsal joints.
  - There is pain on palpation and with range of motion, aggravated

    not only during level walking but with activities that require heel rise, such as stair ascent.
  - Patients with hallux rigidus have pain of the first MTP joint with reduced sagittal motion.
  - Pain is most pronounced at the extremes of motion, but as the disease progresses, pain becomes continuous throughout the full arc of motion.
  - Generally, patients with post-traumatic arthritis tend to be younger than those presenting with primary OA.
- The clinical presentation of talar osteonecrosis is primarily determined by the integrity of the articular surface.
  - Before articular collapse, the patient may be asymptomatic.
  - The pain and mechanical symptoms associated with increasing articular incongruity typically represent the primary complaints.

Imaging

- Initial imaging comprise of plain radiographs: weightbearing AP, lateral and oblique x-rays of the foot, as well as AP, lateral, mortise views of ankle.
- CT scan can be useful for assessing joint-surface defects, degenerative joint changes, and location of osteophytes.
- MRI often obtained in osteonecrosis, where it can help determine not only its presence, but also the extent of involvement and/or bone loss.

Classification/Imaging Findings

- Kellgren–Lawrence Grading Scale
  - System for grading OA based on x-ray, looking specifically at joint space narrowing, osteophytes, and sclerosis of bone.
    - Grade I: Doubtful narrowing of joint space and possible osteophytic lipping

    - Grade II: Definite osteophytes, definite narrowing of joint space
    - Grade III: Moderate multiple osteophytes, definite narrowing of joint space, some sclerosis, and possible deformity of bone contour
    - Grade IV: Large osteophytes, marked narrowing of joint space, severe sclerosis, and definite deformity of bone contour
- There are classification systems for nearly all pathology of the foot & ankle.
  - E.g.: Coughlin & Shurnas classification of hallux rigidus, the Hawkins classification of talar neck fractures, and the Smillie classification for Freiberg disease.
  - The Kellgren–Lawrence system is a general OA-staging system that is widely applicable to a variety of degenerative conditions throughout the body.
- Regardless of the cause of osteonecrosis, the final radiographic finding remains the same: a resultant relative increase in the radiodensity of the bone.
  - Conventional radiographs are useful for diagnosis only after the development of sclerosis, articular collapse, or a crescent sign.
  - MRI may show diffuse marrow edema in early osteonecrosis, low signal intensity on T1-weighted images, and high signal intensity on T2-weighted images.
    - In advanced stages of the disease, both T1- and T2-weighted images demonstrate low signal intensity.
    - Subchondral lucency (i.e., Hawkins sign) seen at 6 wks after injury is reliable evidence of revascularization.

Nonoperative Treatment

- Nonoperative treatment of foot/ankle arthritis should begin here.
- This typically consists of anti-inflammatory medications, ice, activity modification, intra-articular injections, shoe modifications, and orthotics.
- Shoes with a cushioned heel and a stiff, rocker bottom sole can be

used, and if not effective, more intense immobilization with a molded ankle–foot orthosis or double-upright brace may be used.

- These tend to decrease joint inflammation and pain by restricting ankle joint motion.

Operative Indications

- Operative options: Considered when patient has failed nonoperative treatment or deformity/pain severe

1. **Ankle arthroscopy:** Can evaluate joint surfaces and perform debridement/removal of loose bodies, as well as osteophyte resection, arthrodesis, and other procedures such as core decompression.
2. **Ankle arthrodesis:** Gold standard of treatment for end-stage ankle arthritis; may be indicated in osteonecrosis as well.
   - *Principal indication:* Persistent ankle pain/stiffness that is functionally disabling and not alleviated by nonoperative treatments.
     - It provides reliable relief of pain and return to activities of daily living.
   - *Disadvantage:* Increased risk of arthrosis in adjacent joints.
   - *Techniques:* Arthroscopic, mini-open, open, and fusion using external fixator.
     - Various fixation devices include plates, screws, intramedullary nails, angled blade plate.
3. Ankle arthroplasty:
   a. Distraction arthroplasty (joint intermittently distracted in small increments to induce chondral regeneration via chondrocytes' response to intermittent hydrostatic pressure)
   b. Allograft arthroplasty
   c. Total ankle arthroplasty (relieves pain, preserves motion at talocrural joint).
      - *Contraindications:* infection, neuromuscular dysfunction,

Charcot arthropathy, severe osteopenia, osteonecrosis of the talus, and prior arthrodesis.

4. **Arthrodesis of midfoot structures:** Fusion of medial/middle columns
5. Treatment of hallux rigidus:
   a. Joint-sparing procedures (cheilectomy, periarticular osteotomies)
   b. Joint-destructing procedures (arthrodesis)
   c. Joint-altering procedures (Keller resection arthroplasty, interpositional arthroplasty, total joint arthroplasty, hemiarthroplasty)

Surgical Technique

- Selection of the surgical technique should be based on the underlying disorder.
  - As a general rule, external fixators are preferred for patients undergoing arthrodesis for a pre-existing septic joint and for those with severe osteopenia.
  - Arthroscopic arthrodesis or the "mini-open" arthrodesis should be used only for patients with minimal deformity.
    - Open arthrodesis is appropriate for patients with significant ankle deformity and foot and ankle malalignment.
  - Regardless of the surgical technique chosen, the optimal postoperative position of the affected foot and ankle joint is the same.
    - The ankle should be in neutral flexion (0 degrees) with 5–10 degrees external rotation and 5 degrees valgus.
    - This position provides the best extremity alignment and accommodation of hip and knee motion.
- Other procedures
  - Cheilectomy: Around 30% of dorsal MT head articular surface removed +/− proximal phalanx dorsal wedge osteotomy.

- Keller resection arthroplasty: Removal of base of proximal phalanx; decompresses joint, increases range of motion; can lead to cock-up deformity, toe-off weakness, and transfer metatarsalgia.
- Interpositional arthroplasty: Cheilectomy, resection of phalangeal base, and placement of a biologic spacer. Complications: Transfer metatarsalgia, decreased toe-off strength, hallux cock-up.

Postoperative Rehab and Expectations

- The most common complication in ankle fusion surgery is nonunion; some studies report nonunion rates at high as 40%.
  - Other complications include: infection, neurovascular injury, malunion, wound-healing problems.
  - After midfoot surgery, nonunion also a risk (3–7%), with added risks of post-op neuroma, symptomatic hardware, as well as the risks described above for ankle fusion.
- Regardless of surgical intervention, patients are maintained non-weightbearing postoperatively.
  - This ranges from 6 wks in more minor surgeries to upward of 3 mo with arthrodesis.
  - In general, fusion rates of 75% to 100% are reported, with time to fusion of approximately 16 wks.
  - Satisfaction rates of ≥82% and return to work of ≥80% of patients have been reported, with significant functional improvement.
  - TAA is continually improving, with short-to-intermediate follow-up but no significant, well-designed long-term studies of effectiveness and longevity of the implants.
  - The 5-yr prosthesis survival rates are reported between 78 and 88.

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INITIAL EVALUATION AND TREATMENT OF SPINE INJURIES

FERNANDO TECHY

Anatomy and Pathoanatomy

Spine fractures usually result from high-energy trauma, although osteoporotic fractures can occur from low-energy mechanisms. Prior to orthopaedic or neurosurgical evaluation, the patient should be accessed by a Trauma Surgeon, and ATLS guidelines should be followed in order to quickly and accurately rule out other life-threatening injuries. All trauma patients should initially be treated as if they have an unstable spine injury, and immediate spine precautions and immobilization should be implemented at the site of the incident. The head and neck should be aligned with the axis of the trunk and immobilized in that position with a rigid cervical collar. Children have a relatively larger head:body ratio and their torso should be elevated on the board to avoid excessive neck flexion (place a towel behind the shoulders). In football players, the helmet should not be removed on the field to access the airways as it will cause excessive extension due to the presence of the shoulder pads. The facemask should be removed with a screwdriver instead. The helmet and pads should only be removed by trained personnel.

History and Physical

- After the initial ATLS evaluation, the physical exam consists of a complete neurologic assessment.
  - This includes a comprehensive motor, sensory, and reflex examination.

- Other positive signs are:
  - Pain on palpation of the spinous processes
  - Presence of ecchymosis
  - Palpation of a gap between and/or widening of the spinous processes, which represents a posterior ligamentous complex injury

Clearing The Cervical Spine

There are four "types" of trauma patients who require cervical spine clearance (Table 7.1).

Table 7.1 Classifications of Trauma Pts who Require Cervical Spine Clearance

Classification	Important Characteristics	Treatment
(1) Asymptomatic	Awake and Alert, No neck pain, Normal neurologic exam, No intoxication, No distracting injuries.	If no neck pain, and pain-free axial rotation 45 degrees to right and left, no imaging needed. Can clinically clear cervical spine.
(2) Temporarily nonassessable	Asymptomatic, intoxicated, or has distracting injuries; Expect resolution in 24–48 hrs.	Keep in cervical collar and maintain spine precautions until intoxication and/or distracting injuries abate. Then examine patient. If asymptomatic, clinically clear spine. If neck pain, keep in collar and refer to spine specialist.
(3) Symptomatic	Cervical pain or tenderness, Neurologic deficits.	Keep in cervical collar and maintain spine precautions, Obtain appropriate imaging (likely CT scan), refer/consult to spinal specialist.
(4) Obtunded	Abnormal cognitive function that interferes with clinical exam.	Keep in cervical collar and maintain spine precautions. If expected to remain obtunded for >48 hrs, then may need MRI to accurately clear cervical spine.

Anderson PA, Gugala C, Lindsey RW, et al. Clearing the cervical spine in the blunt trauma patient. *JAAOS*. 2010;18:149–59.

Imaging

- A lateral c-spine x-ray is part of the ATLS protocol.
- Currently, most blunt trauma patients are evaluated with a CT scan upon presentation to the emergency department.
  - This modality offers better visualization of the craniocervical and cervicothoracic junctions, which are often difficult to assess on plain radiographs.
- An MRI is useful to evaluate a patient with neurologic injury, and to rule out injury to the posterior ligamentous complex (supraspinous and interspinous ligaments, ligamentum flavum, and facet capsules).
- It is important to note that not all trauma patients require advanced imaging, and these studies should be performed only if indicated.
- If there is concern for instability, upright x-rays in a cervical collar should be performed to look for any evidence of subluxation/translation/kyphosis.

Pharmacologic Intervention For Spinal Cord Injury

- The basis for pharmacologic treatment after a spine fracture with neurologic deficit is to interrupt the subsequent inflammatory cascade that is reparative but also contributory to further injury.
  - Many experimental substances have been investigated but only a few have shown results satisfactory enough to prompt clinical trial.
  - The most studied substance is methylprednisolone.
  - In three large prospective randomized trials known as the National Acute Spinal Cord Injury Studies (NASCIS), there has been statistically significant with, however, minimal clinical difference favoring the group that received steroids.
- Several other studies show no clinical difference and elevated complication rates when steroids are used.
- These results make steroid use very controversial in the current management of acute spinal cord injury.

- Other substances that have been tested but did not show sufficient promise to become relevant for clinical use include:
  - 21 aminosteroid U 74006 F
  - Gangliosides
  - Tirilazad
  - Naloxone

Classification

ASIA (American Spinal Injury Association) Definitions

- The **Neurologic Injury Level** is the most caudal segment of the spinal cord with normal motor and sensory function on both sides: right and left sensation and motor function.
- **Complete Injury:** Absence of sensory and motor function at the lowest sacral segment.
- **Incomplete Injury:** Presence of, at least partial, either sensory or motor function at the lowest sacral segment.
- **Perineal sensation:** Pinprick and light touch in S2–S4 (saddle region of posterior thighs, buttocks, and rectum)
- **Sacral motor function:** Voluntary anal sphincter contraction.
- Incomplete injuries have better recovery prognosis.
- **Spinal Shock:** Loss of spinal function and reflexes distal to the spinal cord injury.
  - Spinal shock usually resolves within 24–48 hrs from the injury.
  - After the spinal shock has resolved, the peripheral reflexes return even in the presence of a complete spine injury.
  - A present anal contraction when stimulating the glans or clitoris indicates a positive bulbocavernosus reflex and that the spinal shock has resolved.
  - The lesion will be classified as complete or incomplete depending on the sacral sensation and motor function.
  - If the bulbocavernosus reflex is absent, it means that the patient is

still in spinal shock and will need future prognostic evaluation.

- **Neurogenic Shock:** Hypotension associated with loss of peripheral vascular resistance due to acute dysfunction of the sympathetic nervous system after brain or spinal cord injury.

Surgical Treatment

- In general, indications for surgery in the setting of spine trauma are:
  1. Instability
  2. Neurologic injury
  3. Pain associated with progression of deformity
- The timing for surgical intervention remains controversial.
  - With that said, recent evidence suggests that early decompression and stabilization provides better outcomes to delayed treatment.
- Despite all controversy, most centers will operate on unstable injuries (complete or incomplete) as soon as the patient is medically stable.
  - Incomplete injuries are usually decompressed and stabilized sooner due to better recovery prognosis.

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CERVICAL SPINE TRAUMA

JASON W. SAVAGE

Introduction

Injuries to the cervical spine occur in approximately 2–6% of blunt trauma patients. It is estimated that 150 k cervical spine injuries occur each year in the United States, and 11 k are associated with a spinal cord injury. The potential for instability and/or neurologic compromise makes prompt identification and judicious management critically important in this population. Approximately two-thirds of all fractures and three-fourths of all dislocations occur within the subaxial spine (C3–C7). Developing an algorithm for the evaluation and treatment of these injuries is paramount and will ultimately help guide the initial evaluation and treatment of these patients.

The purpose of this chapter is to provide the reader with a brief overview on some of the relevant topics in cervical spine trauma. It is *not* meant to serve as a comprehensive source to guide definitive management of these complex injuries.

Anatomy and Pathoanatomy of The Upper And Subaxial Cervical Spine

- The upper cervical spine is a relatively complex three-unit joint that includes the bones of the occiput, atlas (C1), and axis (C2), their synovial articulations, and associated ligamentous structures.
  - Occiput-C1 articulation supplies approximately 50% of total cervical flexion and extension
  - C1–C2 articulations supply 50% of total cervical rotation.
- The majority of mechanical stability of the craniocervical junction

(CCJ) is provided by the investing ligamentous structures.

- The *anterior longitudinal ligament* attaches to the anterior body of the axis, the anterior arch of the atlas, and the inferior edge of the foramen magnum. It terminates as the anterior atlanto-occipital membrane.
- The *tectorial membrane* is the broad cephalic extension of the posterior longitudinal ligament, and runs along the posterior surface of the vertebral bodies, including the dens, and attaches to the anterolateral edge of the foramen magnum.
  - It is the primary stabilizer of the occiput-C1 articulation and helps to limit extension.
- The *cruciate ligament complex* is composed of vertical and transverse components.
- The transverse portion is commonly referred to as the *transverse atlantal ligament* (TAL), which runs between the lateral masses of the atlas posterior to the dens.
  - It is the primary stabilizing ligament of the atlantoaxial motion segment and minimizes flexion, translation, and distraction, but allows rotation.
- The *alar ligaments* arise from the dorsolateral aspect of the dens and attach to the inferomedial aspect of the occipital condyles and are important stabilizers of the CCJ.

- In general, the subaxial cervical spine can be separated into four distinct anatomic regions.
  - The *anterior column* consists of the vertebral body, anterior and posterior longitudinal ligaments, intervertebral disk, uncinate processes (joints of Luschka), and transverse processes.
  - Its primary function is to bear compressive loads.
  - The *posterior column* includes the posterior spinous processes, lamina, ligamentum flavum, interspinous ligaments, and ligamentum nuchae.
  - The *right and left columns* include the pedicles, lateral masses (bone between the superior and inferior articular processes), facet joints, and joint capsules.

- Unique to the cervical spine are the foramen transversarium, which house, the vertebral arteries.
- In approximately 92% of patients, the vertebral arteries pass anterior to the transverse process of C7, and enter the transverse foramen at the C6 level.
  - The arteries then travel cephalad in the transverse foramen, course obliquely and medially on the superior aspect of the posterior arch of C1, and enter the foramen magnum, where they join in the midline to form the basilar artery.

Differential Diagnosis

- Neck pain is a relatively common complaint amongst the general population.
- In the setting of blunt trauma, an acute cervical spine injury (fracture and/or ligamentous disruption) must be ruled-out.
- Other common causes of neck pain include a herniated disk, paraspinal muscle strain, and/or underlying cervical spondylosis/arthritis.
- Less likely causes of neck pain or instability include infection, metastatic disease, or primary neoplasms of the spine.

Cervical Spine Stability

- Spinal stability is defined as the "ability of the spine under physiologic loads to limit patterns of displacement so as not to damage or irritate the spinal cord or nerve roots and, in addition, to prevent incapacitating deformity or pain due to structural changes" (White and Panjabi, 1990).
- Historically, spinal instability has been defined as angular displacement greater than 11 degrees compared with an adjacent vertebra or vertebral body translation greater than 3.5 mm.
- In general, the cervical spine is considered to be mechanically unstable if there is any significant change in alignment (translation, subluxation, rotation, facet joint widening, segmental kyphosis, etc.), or if there is neurologic compromise (spinal cord or nerve root injury) due to a traumatic event.

Initial Evaluation and Physical Exam

- Examination of the patient with a suspected cervical spine injury should begin with adherence to the Advanced Trauma Life Support (ATLS) protocol, as many of these patients have other injuries, including noncontiguous spine injuries, which occur in approximately 10% of patients.
  - When appropriate, the immobilization collar should be carefully removed, and the posterior cervical spine palpated for tenderness along the midline and paraspinal musculature.
  - The examiner should note any angular or rotational deformities (i.e., position of the head), and evaluate for any evidence of stepoff between the spinous processes, which may indicate ligamentous injury.
  - A thorough upper and lower extremity motor and sensory exam should be performed, and any appreciable deficits should be immediately noted.
- A rectal and perineal examination should also be documented, and the examiner should evaluate for any evidence of spinal cord dysfunction by trying to elicit a variety of pathologic reflexes (Hoffman's, inverted brachioradialis, bulbocavernosus, hyper-reflexia, clonus, Babinski, etc.).
- Spinal cord injury should be characterized according to the American Spinal Injury Association (ASIA) impairment scale (whereas ASIA A is a complete spinal cord injury, ASIA B through D are incomplete injuries, and ASIA E is normal).
  - The level of injury is documented as the most caudal level with normal motor and sensory function (i.e., a patient with C6 quadriparesis has normal function of C6, and impaired function at and below C7).

Imaging

- A number of imaging modalities are available for evaluating the cervical spine in the setting of trauma.
- Unfortunately, determining the appropriate protocol for their use

remains controversial.

- In general, a cross-table lateral radiograph that provides visualization from the occiput to the cervicothoracic junction (superior aspect of T1) is adequate for initially identifying most cervical spine injuries.
- The use of computed tomography (CT) and magnetic resonance imaging (MRI) scans have become popular because of their superior ability to characterize the bony and soft tissue anatomy (posterior ligamentous complex, intervertebral disk, and neural elements), respectively.
- CT scan, in particular, is useful in identifying subtle bony abnormalities and evaluating the cervicothoracic junction, which is often difficult to visualize on plain radiographs.
- The overall sagittal and coronal alignment of the spine, as well as the relationship of the facet joints should be scrutinized on all imaging studies.
  - A Cobb angle can be used to measure local/segmental alignment. Upright (sitting or standing) x-rays can also be obtained to evaluate for any evidence of dynamic instability.
  - If there is any question of significant bony or ligamentous injury, the spine should be immobilized in a collar and a specialist should be consulted for definitive care.

Clearing The Cervical Spine

- The primary goal of clearing the cervical spine is to accurately confirm the absence of a cervical spine injury.
  - In other words, the objective is to establish that an injury does not exist.
  - Immobilization in a cervical collar should be initiated at the scene of the injury and maintained until an appropriate evaluation (clinical exam with or without radiographs) has been performed.
- There is good evidence that the asymptomatic patient can be reliably cleared by clinical exam alone without imaging.
  - If the patient has no evidence of intoxication or distracting injury,

no midline tenderness on exam, and no pain with active axial rotation, flexion, and extension, the cervical spine can be cleared, and no immobilization is necessary.

- If the patient is intoxicated and/or has a distracting injury, clearance should be delayed until an accurate evaluation/exam can be obtained (usually within 48 hrs).

Imaging

- If the patient is symptomatic (has neck pain, tenderness, or neurologic symptoms), imaging studies are required.
  - Options include plain radiographs, CT, and/or MRI.
  - In the setting of neck pain with a negative CT scan, it is general practice to maintain the patient in a rigid cervical collar, and obtain flexion–extension x-rays in the subacute period (~2 wks after the injury), to rule-out an occult ligamentous disruption.
- The obtunded patient often requires advanced imaging (CT and/or MRI) to adequately clear the cervical spine, in light of not being able to perform an adequate clinical exam due to their altered mental status.
- If there is any question about whether or not a cervical spine injury exists, cervical immobilization should be maintained, and the patient should be referred to a spine specialist for definitive evaluation, management, and clearance.

Classification Systems for Cervical Spine Trauma

- The most widely used classification system was proposed by Allen and Ferguson, and includes six types of injuries:

1. Flexion–compression
2. Vertical compression
3. Flexion–distraction
4. Extension–compression
5. Extension–distraction

6. Lateral–flexion

- More recently, the subaxial cervical spine injury classification system (SLIC) was developed, and focuses on:
  - the morphology of injury (compression fracture, burst fracture, flexion–distraction injury, or rotational injury)
  - integrity of the discoligamentous complex
  - neurologic status of the patient.
- This system is extremely useful in that it helps elucidate the important factors that go into clinical decision-making, most notably the integrity of the ligamentous complex and neurologic status of the patient.

Nonoperative Treatment

- Many cervical spine injuries can be managed nonoperatively. If the patient is neurologically intact, and there is no evidence of instability on plain radiographs and/or advanced imaging (CT or MRI), nonoperative treatment with a cervical orthosis is likely the best course of treatment. Upright x-rays should be obtained prior to discharge to ensure that no dynamic instability is present (meaning that there is no change in alignment with gravity). In general, flexion and extension x-rays should not be done in the acute setting. Close clinical and radiographic follow-up is necessary to evaluate for any signs of late instability and/or neurologic compromise.

Operative Indications

- Deciding between surgical and nonsurgical intervention is often complicated, and requires an individualized, rational treatment strategy.
  - In general, it is helpful to consider the following simple questions:
    1. Is there evidence of mechanical instability?
    2. Is there neurologic compromise requiring decompression?
  - If the answer to either of these questions is “yes,” then surgical

intervention is likely warranted.

  - If the answer to both of these questions is “no,” then treatment would most often consist of a form of cervical immobilization for a period of 6–12 wks (depending on the nature and severity of the injury).

- In other words, if there is any evidence of mechanical instability (significant loss of vertebral body height, vertebral body translation, rotation, facet joint widening, subluxation or dislocation, segmental kyphosis, or overall change in alignment) and/or signs of neurologic compression or compromise (nerve root injury causing pain/weakness/numbness, spinal cord dysfunction), surgical intervention should be considered.

Surgical Technique

- A variety of surgical techniques are available to treat cervical spine trauma, the details of which are beyond the scope of this chapter.
- In general, the goals of surgery are to decompress the neural elements when necessary, and provide structural stability to the spine.
  - This can often be accomplished through an anterior, posterior, or combined approach.
  - This may include anterior cervical diskectomy and fusion (ACDF), corpectomy and fusion, or posterior stabilization (lateral mass screws, pedicle screws, pars screws, etc.) with or without decompression.
- The surgical plan, including the specific methods of decompression and fusion, is dictated by many factors, and is very patient specific.

Postoperative Rehab and Expectations

- In the setting of a spinal cord injury, an extensive and focused rehabilitation program is required to help the patient optimize his/her outcome.
- Psychosocial support is paramount during the first 12 mo following

injury, as the incidence of severe depression is highest during this time period.

- In the absence of spinal cord injury, the rehab protocol is generally divided into 4 phases:
  1. the protection phase
  2. the motion phase
  3. the strengthening phase
  4. the return to activity phase
- Progression from one phase to the next depends on meeting certain criteria and is entirely patient dependent.
- Not all patients who sustain a cervical spine injury require a formal rehabilitation program, and therefore, each case should be considered individually.

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CERVICAL SPONDYLOSIS, HERNIATED NUCLEUS PULPOSUS, AND SPONDYLOLISTHESIS

JASON W. SAVAGE

Introduction

Degeneration of the intervertebral disc is a normal function of aging and is quite prevalent in the general population. Patients with cervical spine-related problems may have axial neck pain, radiculopathy, myelopathy, or a combination thereof. Axial neck pain refers to pain along the spinal column and its associated paraspinal musculature. Cervical radiculopathy is often characterized by pain that radiates down an upper extremity in a specific dermatomal distribution and may be associated with motor and/or sensory deficits. Myelopathy is the development of spinal cord dysfunction due to an array of pathologic conditions that ultimately cause spinal stenosis.

Anatomy and Pathophysiology

Cervical spondylosis is the broad term used to describe the degenerative changes that are often seen in the aging cervical spine. The inciting event is usually degeneration of the intervertebral disk, which causes an alteration in biomechanics and force transmission. This, in turn, leads to hypertrophy and/or incompetence of the uncinate processes, facet joints, and ligamentum flavum.

Axial neck pain is often caused by degeneration of the intervertebral disk, disk herniation, and/or paraspinal muscular strain.

Cervical radiculopathy, or nerve root compression, may occur through several different causes. First, nuclear material from an acute "soft" disc herniation may impinge on the exiting nerve root as it travels in the spinal canal or enters the neuroforamen. Second, a chronic or "hard" disc herniation, caused by annular bulging with or without osteophyte formation may compress the nerve roots. Finally, the uncinate processes may hypertrophy and cause foraminal stenosis, as they form the floor of the neural foramen.

Cervical myelopathy is often caused by degenerative changes that result in spinal stenosis (uncinate process and facet hypertrophy, osteophyte formation, thickening/buckling of the ligamentum flavum, and/or disc herniation), ossification of the posterior longitudinal ligaments (OPLL), instability with or without cervical kyphosis, and/or congenital stenosis.

Spondylolisthesis is the term used to describe when one vertebral body "slips" or translates on another (anterolisthesis = anterior translation of the cephalad vertebra, retrolisthesis = posterior translation, laterolisthesis = lateral translation). It is either caused by trauma, or is a result of incompetence of the facet joints due to the degenerative process (involving the intervertebral disks, facet joints, uncinate processes, ligaments, etc.). The instability associated with spondylolisthesis may cause axial neck pain as well as central/foraminal stenosis.

Clinical History

- Patients will often present with a compilation of symptoms, which may include neck pain, arm pain, numbness/tingling, weakness, headaches, issues with balance, and/or difficulty using their hands.
- The duration, severity, and nature of the symptoms should be elicited. It is very important to determine how much neck pain versus arm pain the patient is having, as this will help guide treatment.
- One should also inquire about signs of myelopathy, which include ataxia (balance problems with walking, broad-based gait), loss of fine motor skills (inability to button shirts, hand writing, etc.), and

bowel/bladder dysfunction.

Differential Diagnosis

- Axial neck pain
- Cervical radiculopathy
- Cervical myelopathy
- Muscular strain
- Primary or metastatic bone tumors
- Discitis
- Vertebral body osteomyelitis
- Epidural abscess
- Shoulder pathology (AC joint arthritis, rotator cuff tendinopathy, etc.)
- Multiple sclerosis
- Thoracic outlet syndrome
- Peripheral entrapment neuropathies (cubital tunnel syndrome, carpal tunnel syndrome, etc.).

Physical Exam

- The physical exam should always start with evaluating the patient's gait.
  - Patients with cervical myelopathy often have an ataxic gait (slow, wide-based, and shuffling in nature) and have difficulty with balance (unable to perform tandem gait, or fast paced gait).
- The range of motion of the neck should be documented.
  - Patients with significant spondylosis will often have limited flexion and extension, with or without pain.
  - A *Spurling test* is positive when neck extension and lateral bending produces radicular pain down the affected extremity in a dermatomal distribution.

- A thorough motor and sensory exam should be performed and strength should be graded (on a scale from 0–5) for the deltoids (C5), biceps (C5, C6), triceps (C7), grip (C8), and hand intrinsics (T1).
- One should try to elicit any pathologic reflexes (Hoffman's, inverted brachioradialis, hyper-reflexia, clonus, Babinski, etc.).
  - Other signs of myelopathy include a positive Lhermitte test ("shock-like" sensation that radiates into arms and legs with neck flexion or extension), a slow grip-release test (a patient should be able to rapidly open and close their hands 20 times in 10 s).
  - Provocative testing for peripheral neuropathies should also be performed to rule-out confounding diagnoses (Tinel sign at the elbow and wrist, median nerve compression test, etc.).
  - Finally, a shoulder exam will help rule-out rotator cuff pathology as a potential confounding source of pain.

Imaging

- Radiographic changes of cervical spondylosis are age-related and occur in most people over the age of 50.
- Plain x-rays should be the first line of radiographic evaluation.
  - The AP view allows identification of cervical ribs, scoliosis, and the size of the uncovertebral joint hypertrophy.
  - The lateral view is more useful, in that it demonstrates the degree of disk space narrowing, subchondral sclerosis, the size of the endplate osteophytes, size of the spinal canal, and presence of OPLL.
- Advanced imaging modalities (CT and MRI scans) are often useful.
  - CT scans allow for better characterization of the bony anatomy (especially the disc–osteophyte complexes and uncovertebral joints)
  - MRI is great for evaluating the soft tissue structures (intervertebral disc, ligaments, epidural space, etc.), sites of neurologic compression, and/or cord abnormalities.

- In general, MRI is warranted if the patient has
  - persistent neck or arm pain (present for more than 2 or 3 mo)
  - neurologic findings (weakness or paresthesia)
  - any evidence of myelopathy (to evaluate for severity of stenosis and/or evidence of cord signal change/dysfunction)
  - a worsening symptomatic picture

Nonoperative Treatment

- In the absence of myelopathy, a 3–6-mo course of nonoperative management should be attempted for most degenerative cervical spine disordersd/o.
- This may include any of the following, alone or in combination:
  - immobilization (soft collar)
  - traction
  - medication (NSAIDs)
  - physical therapy
  - cervical manipulation (chiropractic care)
  - corticosteroid injections
- Injections are particularly useful in that they often serve a diagnostic and therapeutic purpose.
  - For example, a *successful* right-sided C6 nerve root injection will alleviate the patient's symptoms and identify the level of inciting pathology, which in this scenario, would most likely be a right-sided C5–C6 disk herniation.
- In general, neurologic symptoms should drive surgical decision making, and not the mere presence of axial neck pain.

Operative Treatment

- Commonly accepted indications for surgery include severe or progressive neurologic deficit (weakness or numbness) or significant pain that fails to respond to nonsurgical treatment.

- In general, significant instability is present if there is greater than 3.5 mm of sagittal plane translation (spondylolisthesis) and/or 11 degrees of segmental angulation or kyphosis.
- Furthermore, a patient who has signs/symptoms of cervical myelopathy will often require surgical intervention in an attempt to prevent any progression of neurologic compromise.

Surgical Technique

- There are many surgical options for treating degenerative conditions of the cervical spine.
- Deciding between surgical and nonsurgical intervention is often complicated, and requires an individualized, rational treatment strategy.
- The decision-making process often revolves around
  - the symptomatology of the patient
  - the sites of neurologic compression (anterior versus posterior)
  - the number of vertebral segments involved (single level versus multilevel)
- The following is a brief description highlighting the key steps in performing a few of these procedures.
  - By no means is it meant to offer a definitive reference regarding surgical indications and/or techniques.

Anterior Approaches to the Cervical Spine

- Anterior cervical diskectomy and fusion (ACDF):
  - In general, ACDF is the treatment of choice for single- or two level degenerative disk disease that causes axial neck pain, radiculopathy, and/or myelopathy.
  - *Positioning:* supine with the head in slight extension
  - *Surgical exposure:* an anterior approach, which utilizes the interval between the sternocleidomastoid/carotid sheath and the strap

muscles/trachea/esophagus

  - Care must be taken to protect the esophagus and trachea (retracted medially) as well as to avoid injury to the recurrent laryngeal nerves (keep retractor blades deep underneath the longus colli muscles to help prevent this complication).
  - Careful attention should be made to avoid violating the disk space above or below the level of pathology.
- Diskectomy:
  - First, the annulus is incised with a 15-blade scalpel.
  - Distraction pins in the vertebral bodies above and below will help gain access to the disk space (be gentle with distraction).
  - Then, small curettes are used to detach the disk from the cartilaginous endplates.
  - Next, a combination of small curettes and kerrison rongeurs are used to carefully decompress the central canal & and neural foramen.
  - A high-speed bur is often used to take down any overhanging osteophytes (both along the anterior and posterior vertebral bodies).
- *Endplate preparation:* Once the diskectomy is completed, the cartilage must be removed from the endplate, which can be done with a high-speed bur and/or curettes.
- *Graft insertion:*
  - Iliac crest autograft or donated tricortical iliac crest allograft are the two most commonly used grafts for ACDF.
  - The graft is sized with a series of templates, and then fashioned to fit the prepared disk space.
- *Instrumentation:* A variety of plate and screw systems are available to secure the graft in place.
- *Wound closure:* The platysma (with or without a deep drain) and the subcutaneous layers are closed with an absorbable suture, and a sterile dressing is applied.
- *Immobilization:*

    - A cervical collar is not required for a single level ACDF.
    - The use of a collar in multilevel ACDFs is surgeon dependent.
- Anterior Cervical Disk Arthroplasty (ACDA):
  - This newer technique is currently being used for single-level degenerative disk disease.
  - The operation is very similar to that of an ACDF; however, instead of placing a bone graft in the disk space for fusion, a disc arthroplasty is placed in an attempt to restore normal spine biomechanics and maintain motion.
  - At this time, the literature suggests that there is no difference between a single-level ACDF versus ACDA, although long-term results are still pending.
    - There is a 25% incidence of symptomatic adjacent segment degeneration over a 10-yr period following ACDF.

Posterior Approaches to the Cervical Spine

- “Open-door” Laminoplasty:
  - This procedure is mostly used for multilevel cervical spondylotic myelopathy with or without OPLL.
  - Contraindications include evidence of cervical instability (translation and/or subluxation) and/or kyphosis greater than 10 degrees (neutral to lordotic alignment is preferred).
  - *Positioning:* Prone with the head secured in a Mayfield head holder or Gardner wells tongs (with ~10–15 lb of traction)
  - *Surgical approach:*
    - A midline posterior incision is made over the spinous processes.
    - The deep cervical fascia is incised, and care is taken to stay in the midline (there is an avascular raphe) to help minimize bleeding.
    - Identify the bifid spinous processes (C2–C6) and use electrocautery to expose the lamina just out to the medial aspect of the lateral mass (do not violate the facet joints).
    - Keep the supraspinous and interspinous ligaments intact.

- Decompression:
  - A bicortical osteotomy is made in the lamina on the "open door" side of the laminoplasty.
  - This is usually done on the side of the more severe symptoms (i.e., on the right for right > left arm pain).
  - The osteotomy is made using a high-speed bur at the inflection point (at the junction of the lamina and lateral mass).
  - Be careful not to penetrate into the spinal canal, or violate the facet joints.
  - You can use a small kerrison rongeur to complete the osteotomy if needed.
  - A unicortical (just through the dorsal cortex) osteotomy is then performed on the contralateral side.
  - The ligamentum flavum must be released off the undersurface of the cephalad and caudad vertebra involved in the laminoplasty procedure in order to successfully "open" the hinge.
    - Once this is done, you are ready to gently lift the lamina toward the intact hinge (unicortical osteotomy side).
    - This is done with gentle pressure using your thumb and releasing any adhesions underneath the lamina with a small curette.
- *Instrumentation:* The osteotomy is then held open with a small plate secured by screws into the lamina and lateral masses.
- *Immobilization:*
  - A soft cervical collar is used for comfort.
  - The patient is encouraged to work on gentle neck motion, and to focus on maintaining a good posture.

- Posterior decompression and fusion:
  - A posterior decompression and fusion is another surgical option and is often used for multilevel disease associated with a significant amount of axial neck pain and/or cervical instability.
  - The approach is similar to that of a laminoplasty; however, a formal central decompression/laminectomy is performed, and either

pedicle screws or lateral mass screws are used for posterior fixation.

- Local bone graft obtained from the removed spinous processes and lamina is used for the fusion.

Complications

- Potential complications after anterior cervical spine include infection, injury to the recurrent laryngeal nerve, bleeding, pseudoarthrosis, and/or difficulty swallowing.
- The incidence of developing a C5 nerve root palsy is approximately 5% (no difference between anterior versus posterior approach).

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THORACOLUMBAR SPINE FRACTURES

FERNANDO TECHY

Introduction

Thoracolumbar fractures are resultant of high-energy trauma. Before Orthopaedic or Neurosurgical evaluation, the patient should be accessed by a Trauma Surgeon following the ATLS protocol to rule out other life-threatening injuries. 70% of these fractures are the result of MVAs or falls from height. Neurologic injury is present in 15–20% of thoracolumbar fractures.

Anatomy and Pathoanatomy

- The thoracolumbar junction is prone to injury because it is located between the rigid, kyphotic thoracic spine, and the mobile, lordotic lumbar spine.
- The end of the spinal cord, the conus medullaris, is usually located at L1–L2.
  - Below this level is the cauda equina, which consists of the sensory and motor roots of the lumbosacral myelomeres.
- Indications for surgery:
  1. Instability
  2. Progression of deformity
  3. Neurologic compromise

Definitions of Instability and Indications For Surgery

- Denis 3 column model (1983)
  - *Anterior column:* anterior longitudinal ligament (ALL), anterior ½ of vertebral body and disc.
  - *Middle column:* posterior ½ of vertebral body, disc, and posterior longitudinal ligament (PLL).
  - *Posterior column:* lamina, facet joints, and posterior ligaments (supraspinous, interspinous, ligamentum flavum).
  - Instability determined if 2 or more columns are disrupted.
- Types of fractures: (Denis, 1983)
  - Compression: disruption of anterior column (vast majority are stable and with no neuro deficit)
  - Burst: disruption of anterior and middle column (posterior column stability is variable)
    - Greater incidence of canal compromise and neuro deficit.
    - Instability needing surgical treatment:
      - Height loss of the vertebral body >50%
      - Angulation >20 degrees
      - Canal compromise >50%
  - Chance (seat belt): distraction of posterior and middle column.
    - Anterior is intact.
    - Bony: (47% of total) Treated with hyperextension cast or brace due to adequate healing potential.
    - Ligamentous: (11%) Needs posterior fusion.
    - Mixed: (42%) Needs posterior fusion.
  - Fracture dislocation: all 3 columns disrupted.
    - Unstable: 75–100% of neurologic deficit. Needs operative fixation.
- Other classifications:

- McAfee: mechanistic
- Ferguson and Allen: mechanistic
- OTA/AO: A = compression, B = distraction, C = multidirectional.

- TLICS (Thoracolumbar Injury Classification and Severity Score).
  - This is the newest classification system for thoracolumbar trauma (Vacarro et al. Spine 2005).
  - It is very reliable in that it has a 96% of treatment agreement among Spine Trauma Specialists.
  - The system is based on three components of the injury (morphology, integrity of the posterior ligamentous complex (PLC), and neurologic status of the patient. (Table 7.2).

Table 7.2 Thoracolumbar Injury Classification and Severity Score

Component	Qualifiers	Score
Morphology type	—	—
Compression	—	1
—	Burst	1
Translational/rotational	—	3
Distraction	—	4
Neurologic involvement	—	—
Intact	—	0
Nerve root	—	2
Cord, conus medullaris	Complete	2
—	Incomplete	3
Cauda equna	—	3
PLC	—	—
Intact	—	0
Injury suspected/Indeterminate	—	2
Injured	—	3

PLC, posterior ligamentous complex.
Vaccaro AR, Lehman RA Jr, Hurlbert RJ, et al. Spine (Phila Pa 1976). 2005;30:2325–2333.

- TLICS Score:
  - 0–3: nonoperative (+/− orthosis depending on injury)
  - 4: controversial (injury specific, may treat nonoperative or operative)
  - 5 or higher: operative

Treatment Considerations

1. Prospective randomized studies have shown that stable burst fractures with no neurologic deficit have the same outcome when treated operatively or nonoperatively.
2. Posterior surgery (instrumented fusion) is based on using distraction and ligamentotaxis to reduce and treat the fracture. It is best indicated for unstable fractures with the following characteristics:
   - Unstable burst
   - Neurologically intact
   - No need for decompression
   - Soft tissue chance
   - May be attempted for the following:
   - Mild canal compromise with neurologic deficit in which ligamentotaxis may indirectly reduce the fragments.
   - Indirect reduction and instrumentation should be done within 72 hrs of injury.
   - Use longer constructs with posterior approach only (3 above, 2 below).
3. Anterior column reconstruction is likely beneficial when the following is present:
   - Canal compromise greater than 67%.
   - Extensive comminution of the vertebral body.
   - Kyphotic deformity greater than 30 degrees.
   - Delay in surgical treatment more than 4 d.
   - Traumatic disc herniation compressing the cord or nerve roots.
   - Posterior short constructs are acceptable when the anterior column is reconstructed.
   - Supplemental posterior fixation is necessary when the PLC is no longer intact.

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LUMBAR SPONDYLOLISTHESIS

NIKHIL THAKUR

Introduction

Spondylolisthesis, or the pathologic slipping/sliding of one vertebrae over another, is derived from the Greek words *spondylo* (vertebra) and olisthesis (movement or slipping). Slipping of the vertebra can occur in the forward (anterolisthesis) or backward (retrolisthesis) directions. Spondylolysis is derived from the Greek words *spondylo* and *lysis* (break) and indicates a defect in the pars interarticularis region.

Spondylolisthesis typically presents as back and/or leg pain. The two most commonly encountered types of spondylolisthesis are the isthmic and degenerative variety. Isthmic defects are pars-based defects and mostly seen in the L5 pars with resultant spondylolisthesis between L5 and S1 while degenerative slips are often seen between the L4 and L5 vertebrae due to incompetent facets joints, intervertebral discs etc.

Anatomy and Pathoanatomy

- In the normal lordotic lumbar spine, axial load is distributed between the intervertebral discs (⅔ of the force) and the facet joins (⅓ of the force).
  - There are several forces acting on these supporting structures that can contribute to slipping of vertebrae.
  - The facets in the lumbar spine are oriented sagittally and provide resistance to anterior shear in flexion.
  - Also, iliolumbar ligaments attach at the L5–S1 levels and provide additional restraint to forward flexion and lateral motion.

    - However, this restraint can cause additive stress at the adjacent L4–L5 motion segment.
  - Moreover, the lordosis of the lumbar spine leads to a continual downward force with a forward thrust in the lower lumbar vertebrae.
    - The disc–facet complex, pars, pedicle, and normal bony architecture, counteract these additive forces.

Classification

- Defects in the structures listed above can lead to a spondylolisthesis and form the basis of the *Wiltse Classification*.
  - The *Wiltse classification* is most commonly used in describing the etiology of observed spondylolisthesis:
    - Type I—dysplastic or congenital:
      - due to congenital abnormalities of posterior arch of L5 or upper sacrum.
    - Type II—**Isthmic:** involves the pars interarticularis region; subdivided into:
      - IIA: lytic-fatigue fracture of the pars
      - IIB: elongated but intact pars
      - IIC: acute/traumatic fracture of pars
    - Type III—degenerative:
      - the most commonly encountered type in the adult population.
      - *These are due to degenerative and arthritic changes, degenerated disc and facet joints (which are often incompetent).*
    - Type IV—traumatic:
      - fractures of bony structures other than pars (which is a IIC), such as a pedicle fracture, which allows translation of the bony segments.
    - Type V—pathologic:
      - focal or systemic disease, either neoplastic or metabolic, which

results in bony defects.

- *This chapter will focus primarily on degenerative and isthmic spondylolisthesis.*
  - The Meyerding classification characterizes the degree of the slip of the vertebral bodies.
    - I: 0–24%
    - II: 25–49%
    - III: 50–74%
    - IV: 75–99%
    - V: 100% olisthesis, or spondyloptosis
  - Hence a Grade II degenerative spondylolisthesis at L4–L5 refers to anterior translation of the L4 vertebral body between 25% and 49% over the L5 vertebral body.

Clinical History

- Adult patients with degenerative spondylolisthesis present with back and or leg pain, similar to spinal stenosis.
  - It is most often seen at the L4–L5 level.
  - Back pain is often mechanical, worse with sitting or standing when the involved segment is loaded and is often alleviated when the patient is supine.
  - It can also be aggravated with back extension or arising from a seated position.
  - It is important to distinguish from discogenic pain, which is worse with flexion.
  - Leg pain can be radicular or referred in a pattern of neurogenic claudication and is often worse when standing/walking and is alleviated in the supine position.
  - Neurogenic claudication is defined as pain in the lower extremities, numbness/heaviness or weakness and is also relieved in the flexed position ("shopping cart sign").

- It is important to inquire about the patient's bowel and bladder function, which can indicate an insidious onset of cauda equina syndrome (urinary retention with overflow incontinence, lack of bowel control).
- It should be distinguished from vascular claudication, which can also ail this patient population.

- Isthmic spondylolisthesis has a 2:1 male to female predominance and is most common at the L5–S1 level.
  - It is thought to occur as a result of genetic and environmental factors and is rare in individuals of African descent and is seen most often in Alaskan Inuits (26–50%).
  - Teenagers and young adults often present with a dull aching back pain, aggravated with athletic activities involving flexion/extension motion.
  - Football lineman, gymnasts, swimmers, weight lifters, and so forth, have excessive lumbar extension that can result in spondylolysis.
  - Approximately 20% of patients with spondylolysis develop symptoms associated with spondylolisthesis.

Differential Diagnosis

- Includes degenerative disc disease, disc herniation, spinal stenosis, primary or metastatic bone tumors, vascular claudication, paraspinal abscess, muscular strain, discitis, vertebral body osteomyelitis, epidural abscess, etc.

Physical Exam

- First, it is important to assess a patient's gait in the physical exam.
  - A flexed posture while ambulating is often assumed to relieve claudicating symptoms and not by standing still.
  - This is a useful distinction in assessing any contribution by vascular claudication, which occurs at a repeatable distance and is relieved by standing still, which often aggravates neurogenic claudication.

- A waddling gait in a young adult with an isthmic spondylolisthesis can reflect vertical rotation of the pelvis to allow global lordosis and enable a patient to walk upright while short steps are required to accommodate lack of hip extension.
- A crouched gait is often seen with a high-grade slip with hamstring tightness.
- Gait analyses also helps determine motor strength, rule in/out concomitant thoracic or cervical stenosis (ataxic gait).

- Range of motion in the lumbar spine should be assessed.
  - Patients with degenerative spondylolisthesis, unlike isthmic spondylolisthesis, can have normal or hypermobility of the lumbar spine in flexion with lack of stiffness. Extension can often aggravate a patient's symptoms.
  - A step off can often be appreciated in a high-grade slip.
- Motor strength testing and sensory exam are a crucial part of the physical exam.
  - Patients with neurogenic claudication often have a normal motor exam, though weakness of the tibialis anterior and/or extensor hallucis longus indicates compression of the L4 and l5 nerve roots in the lateral recess or neural foramen.
  - Lower extremity reflexes should also be part of the exam.
  - Presence of global motor weakness and pathologic reflexes should raise awareness of a possible thoracic or cervical issue.

Imaging

- Imaging studies should begin with Anterior–Posterior (AP) and lateral x-rays obtained in the standing position.
  - A reduced motion segment in the supine position, especially in low-grade slips, can demonstrate instability when the segment is loaded while standing thus allowing visualization of a symptomatic spondylolisthesis.
  - Flexion–extension views can also help characterize the degree and dynamic nature of the slip.

- An oblique/“ Scottie dog” view is sometimes obtained, and this can help characterize an isthmic defect in isthmic spondylolisthesis.

- Advanced imaging can include a single-photon emission computed tomography (SPECT) scan, which is useful in identifying a lytic defect (isthmic spondylolisthesis) and can be used to determine chronicity of the lesion (acute vs. chronic) though is not as frequently used as the other advanced imaging modalities.
- Other more frequently used modalities are magnetic resonance imaging (MRI) studies that can also delineate location and quality of the lytic defect in the pars, presence of synovial cysts, disc pathology, identifying presence of central, lateral recess, and foraminal stenosis etc.
    - The latter can be ascertained on the T1- and T2-weighted sagittal images; for example, in an L4–L5 degenerative spondylolisthesis, neuroforaminal stenosis can be seen at the L4–L5 neuroforamen containing the L4 nerve root.
- A computed tomography (CT) scan is also useful in outlining bony anatomy.
    - This helps quantify the architecture of the facet joints, the size of the pedicles, neuroforaminal stenosis from enlarged facets joint (superior articular process), calcification of the disc, ossified ligamentum flavum (OLF) etc.
- Both MRI and CT scan are very useful in preoperative surgical planning.

Nonoperative Treatment

- The history that the patient reports is paramount in determining a treatment algorithm.
    - Younger patients with an isthmic spondylolisthesis can be treated with a variety of nonoperative modalities, including observation, bracing or casting, restriction of athletic activities, etc.
    - In the pediatric patient, the following guidelines are often useful:
        - Incidental pars defect can be observed with annual x-rays in a growing child:

- ≤ 25% slip: semiannual x-rays and no activity limitation
- ≤ 50% asymptomatic slip: semiannual x-rays and possible high-risk athletic restriction and avoidance of heavy labor
- ≤ 50% symptomatic slip: bracing/casting, physical therapy, semiannual x-rays till growth spurt is completed, then annually
- > 50%: possible surgery

- Patients with degenerative spondylolisthesis can be managed in several ways.
  - Low back or radicular pain, at first presentation, can be managed with 1–2 d of bed rest, followed by a rehabilitation program that involves core and back strengthening, and activity modification.
  - Anti-inflammatory/oral steroid medications can also be used.
  - Nonimpact exercise, such as stationary bicycle, which promotes flexion, can be useful.
  - Persistence or progression of radicular symptoms can often be managed with epidural/transforaminal corticosteroid injections, which can result in temporary/complete resolution of symptoms.
  - These are less effective in patients with neurogenic claudication or back pain.

Operative Treatment

- Patients who have failed nonoperative management, have progressive neurologic involvement, radiographic progression of a symptomatic slip and a high slip angle (angle between the end plates of the 2 involved vertebrae) have reasonable indications to undergo surgery.
  - In younger patients with isthmic spondylolysis with no observed slip, repair of the pars can be obtained and has been shown to have good results.
  - These techniques involve grafting and wiring from a posterior approach and can be combined with a direct screw insertion technique into the pars to allow healing.

- In patients with a radiographic spondylolisthesis, repair of the pars is not recommended and these patients require fusion surgery.

Surgical Technique

- Posterior approach to lumbar spine
  - Most isthmic and degenerative spondylolisthesis are treated with a posterior-based surgical approach.
    - This technique involves a midline incision over the involved area of the lumbar spine.
    - The dorsolumbar fascia is exposed and is incised, with a Bovie cautery directly over the spinous process.
    - Next, the attachments of the para spinal musculature, including the multifidus, semispinalis, and longissimus muscles are detached off either side of the spinous process, lamina, and pars.
  - The width of the exposure is based on the planned surgery.
  - Patients with a low-grade degenerative spondylolisthesis, with a fixed slip that does not change from supine to standing or with flexion/extension, may get good results from a stand-alone decompression.
    - In such a situation, the exposure can be limited to the medial edge of the facet joints on either side and it is important not to violate the muscle attachments at the facet capsule or the capsule itself.
    - This reduces the chance of creating iatrogenic instability, postoperative pain, etc.
  - In isthmic or mobile degenerative spondylolisthesis, a fusion is often recommended.
    - There are several studies that report improved patient outcomes when a surgical decompression is performed with an instrumented fusion.
    - To achieve this, the exposure has to extend lateral to the facet joints on either side and onto the transverse process, which is

at the caudal end of the facet joint at the level of the pedicle.

- **Decompression**
  - Posterior decompression is performed in the following fashion: the spinous process of the cranial vertebrae of the involved segment is removed first.
    - Next the plane between the ligamentum flavum (which shingles between the cranial and caudal vertebral laminae) and the cranial lamina is developed using curettes.
    - Once this is done, a laminectomy is performed using a combination of leksell rongeur and kerrison rongeurs toward the most cranial margin of the observed stenosis (typically at the cranial margin of the facet).
    - Next, the lateral recess can be decompression using curettes, kerrison rongeurs and/or osteotomes.
    - It is important to remove all ligamentum flavum dorsally, which is often a significant contributor to the stenosis.
  - Foraminal decompression is then obtained using the same techniques at involved levels.
    - This process can be repeated at other levels in multilevel stenosis.
- **Fusion**
  - There are various fusion techniques that are described in the literature.
    - Posterior approach–based fusion techniques range from an uninstrumented intertransverse fusion, instrumented intertransverse fusion, and an instrumented posterior interbody fusion with or without intertransverse fusion.
    - The first two techniques achieve fusion by exposing the cancellous bone of the transverse processes at the two involved vertebrae and implementation of bone graft (local autograft, iliac crest bone graft, bone graft substitutes, etc.).
  - Often, surgeons will add a transforaminal or posterior lumbar interbody fusion (TLIF and PLIF).
    - The author prefers the TLIF approach.

        - In the TLIF approach, the facet on the side of the more symptomatic radiculopathy is removed and the pedicle is skeletonized.
        - The pars of the cranial vertebrae is also removed and the exiting and traversing roots are identified.
        - This is important to do so in order to ensure prevention of neurologic injury during preparation of the disc space and interbody insertion.
        - Next a complete discectomy is performed using a knife and curettes.
        - Sizing guides are used to pick the appropriate interbody size.
    - A PLIF can also be used to insert an interbody.
        - In this technique, less bone is resected in order to get access to the disc but requires more retraction of the nerve than the TLIF approach.
  - Instrumented fusion typically involves the use of pedicle screws and rod technique.
    - These can be inserted with or without the use of fluoroscopy.
    - Cross-links can be used between rods to increase construct rigidity.
    - Recently, pars screws have been used to achieve fixation at the various involved levels as well, though their use is not widespread.
    - If the bony anatomy precludes insertion of pedicle screws, hook and rod technique can be employed.
- **Other fusion techniques**
  - There are other methods to obtain an interbody fusion, which can be used in combination/adjunct to posterior decompression and fusion.
    - These involve an anterior lumbar interbody fusion (ALIF), which is performed through an abdominal approach using a retroperitoneal/trans-peritoneal technique in order to access the L5–L1 or L4–L5 disc space.

    - The retroperitoneal approach is used more frequently and requires mobilization of the peritoneum off the lateral abdominal wall.
    - Often a general surgery or vascular access surgeon is used to obtain exposure.
    - The complete discectomy is performed and there are several commercial implants available to achieve fusion.
    - Recently the use of bone morphogenic protein (BMP)–2 has been reported to have adverse effects when used in conjunction with an ALIF, including retrograde ejaculation in men.
- The ALIF technique can be used in low-grade spondylolisthesis (Grade I–II) but is extremely difficult to use in higher-grade spondylolisthesis.
    - A more recent technique achieves interbody insertion using a lateral trans psoas or psoas sparing approach (commercially referred to as XLIF/DLIF).
    - In this approach, the incision is made laterally and a minimally invasive technique is used to place retractors through or anterior to the psoas muscle.
    - The discectomy and placement of the interbody can be performed through this approach as well. This approach can be used to allow interbody insertion between the L1–L5 levels.

Complications

- Rates of pseudarthrosis vary in the literature between 0% and 25%, with higher rates seen in more sev slips.
- Potential complications after lumbar surgery include infection, neurologic injury with increased radiculopathy, bleeding, cauda equine, failure of hardware, etc.

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LUMBAR SPONDYLOSIS, HERNIATED NUCLEUS PULPOSUS, AND SPINAL STENOSIS

JASON W. SAVAGE

ANATOMY AND PATHOPHYSIOLOGY

The intervertebral disk plays an important role in maintaining spinal mobility and structural stability. It consists of the inner gelatinous nucleus pulposus (type II collagen and proteoglycans) and outer annulus fibrosis (type I collagen). The aging process causes biomechanical changes within the disk and is prone to injury with torsional, axial, and flexion loads. Primary lumbar disk herniation can be classified as central, paracentral, foraminal, or extraforaminal. Paracentral disk herniations are the most common type, because the posterior longitudinal ligament (PLL) is thicker in the midline and has a weak area posterolaterally. Most disk herniations compress the traversing nerve root (i.e., an L4–L5 disk herniation compresses the traversing L5 nerve root). The exception is foraminal or extraforaminal disk herniations, which tend to compress the exiting nerve root (i.e., a foraminal L4–L5 disk herniation compresses the exiting L4 nerve root as it passes beneath the L4 pedicle). An extruded disk is when there is disk material within the canal, outside of the annulus fibrosis.

Spinal stenosis is caused by degenerative changes in the aging spine. Anatomically, this is caused by a reduction in the space available for the neural elements. This includes hypertrophy of the ligamentum flavum and/or facet joints (specifically the medial aspect of the superior articular facet), synovial cyst formation, and/or disk herniation. Spinal stenosis may also be associated with other degenerative conditions, specifically spondylolisthesis. The pressure on the thecal sac (nerve roots) causes mechanical irritation and vascular disruption (ischemia), which leads to dysfunction of the nerve roots, and ultimately symptoms of neurogenic claudication. Spinal stenosis should be characterized as central, lateral recess (subarticular), and/or foraminal. Extension at the lumbar spine decreases the cross-sectional area available for the nerves, and therefore often worsens symptoms.

Clinical History

- Patients will often present complaining of back and/or leg pain.
  - A lumbar disk herniation often causes radicular symptoms (pain, paresthesia, and/or weakness) in a specific nerve distribution (i.e., a paracentral L4–L5 disk herniation will cause pain in the L5 dermatome).
  - These patients will often have a component of low back pain, although the leg symptoms predominate.
  - The symptoms are often worse with sitting, and slightly better with standing.
- Patients with spinal stenosis will often complain of pain in their legs, paresthesia, and/or weakness.
  - These symptoms classically get worse with standing or walking and are relieved with sitting.
  - Patients often feel better leaning forward (shopping cart sign).
  - It is extremely important to ask about bowel and bladder function.
  - Severe stenosis and/or a large disk herniation may cause cauda equina syndrome (bowel/bladder incontinence, urinary retention, leg pain, weakness, and/or saddle anesthesia).
  - This is a surgical emergency.

Differential Diagnosis

- Disk herniation
- Spinal stenosis
- Vascular claudication
- Nerve sheath tumor
- Infection
- Degenerative arthritis of the hip/knee
- Pelvic and sacral disorders
- Diabetic neuropathy
- Peripheral compressive neuropathies
- Cervical myelopathy
- Amyotrophic lateral sclerosis
- Demyelinating disorders
- Retroperitoneal tumors
- Depression
- Conversion disorders
- Malingering

Physical Exam

- The physical exam should always start with evaluation of the patient's gait, and include a full neurologic examination (upper and lower extremities).
- Look for signs/symptoms of cervical myelopathy (ataxia, hyperreflexia, problems with coordination, etc.).
- Patients with spinal stenosis may walk with a forward-flexed posture (this increases the space available for the nerves and often helps alleviate symptoms).
- Evaluate for any points of tenderness, and/or evidence of spondylolisthesis (step-off between the spinous processes).
- A thorough motor and sensory exam should be performed and strength should be graded (on a scale from 0–5) for the iliopsoas

(L1–L2), quadriceps (L3–L4), tibialis anterior (L4), extensor hallucis longus (L5), and gastroc-soleus complex (S1).

- One should try to elicit any lower extremity pathologic reflexes (clonus, Babinski, etc.).
- A straight leg raise (nerve root tension sign) is concerning for a disk herniation (this is done by passively extending the knee while the patient is seated).

Imaging

- Radiographic changes of lumbar spondylosis are age-related and occur in most people over the age of 50.
- Plain x-rays should be the first line of radiographic evaluation.
  - The AP view allows for evaluation of coronal plane alignment and for any evidence of asymmetric disk space collapse (a potential cause for degenerative scoliosis and/or foraminal stenosis).
  - The lateral view is useful in that it demonstrates the degree of disk space narrowing, subchondral sclerosis, size of the endplate osteophytes, size of the spinal canal, and presence of instability (spondylolisthesis).
  - The lumbar spine should have approximately 40–60 degrees of lordosis.
- Advanced imaging modalities (CT and MRI scans) are often useful.
  - CT scans allow for better characterization of the bony anatomy.
  - MRI is great for evaluating the soft tissue structures (intervertebral disc, ligaments, epidural space, etc.), and sites of neurologic compression.
- In general, MRI is warranted if a patient has persistent leg pain (present for more than 2 or 3 mo), neurologic findings (weakness or paresthesia), bowel/bladder dysfunction, or a worsening symptomatic picture.

Nonoperative Treatment

- In the absence of cauda equina syndrome and/or a significant neurologic deficit, a 6- to 12-wk course of nonoperative management should be attempted for most disk herniations and/or degenerative conditions of the lumbar spine.
- This may include
  - medication (NSAIDs)
  - physical therapy (extension exercises for disk herniations and flexion exercises for spinal stenosis)
  - manipulation (chiropractic care), and/or
  - corticosteroid injections
- Approximately 65–70% of patients with an acute lumbar disk herniation will have resolution of their symptoms over a 3–6 mo period.
- Injections (epidural, transforaminal, or selective nerve root blocks) are particularly useful for patients with spinal stenosis in that they often serve a diagnostic and therapeutic purpose (e.g., a *successful* right-sided L5 nerve root injection will alleviate the patient's symptoms and identify the level of inciting pathology, which in this scenario, may be from right-sided L5 foraminal stenosis).
  - Injections are not particularly helpful in treating acute disk herniations.
- In general neurologic symptoms should drive surgical decision-making, and not the mere presence of low back pain.

Operative Treatment

- Commonly accepted indications for surgery include
  - severe or progressive neurologic deficit (weakness or numbness) and/or
  - significant leg pain that fails to respond to nonsurgical treatment.

Surgical Technique

- There are many surgical options for treating degenerative conditions of the lumbar spine.
- Deciding between surgical and nonsurgical intervention is often complicated and requires an individualized, rational treatment strategy.
- The decision-making process often revolves around the symptomatology of the patient, the sites of neurologic compression, and the number of vertebral segments involved (single level versus multilevel).
- The following is a brief description highlighting the key steps in performing a few of these procedures. By no means is it meant to offer a definitive reference regarding surgical indications and/or techniques.

Lumbar Disk Herniation

- Microdiskectomy:
  - In general, a microdiskectomy is the treatment of choice for a patient who has persistent radiculopathy and/or weakness that does not respond to nonoperative treatment (6–8 wks).
  - *Positioning:* prone (Andrew frame, Jackson table, or Wilson frame)
  - *Surgical exposure:*
    - The correct level is first identified with an intra-operative x-ray (this can either be done prior to incision by marking a spinous process with an 18-gauge spinal needle, or after initial exposure).
    - A midline incision is made and the lumbodorsal fascial is incised on the appropriate side of the spinous process (on the right of L5 for a right-sided L5–S1 disk herniation).
    - Use a cobb elevator to place the paraspinal muscles on tension, and subperiosteally dissect down the spinous process to the inferior aspect of the lamina (L5 for an L5–S1 microdiskectomy).
    - Then place retractors (i.e., McCullough blades). Identify the interlaminal space (i.e., between L5–S1 for an L5–S1

microdiscectomy) and look for the ligamentum flavum (attaches to the leading edge of the caudal lamina and underneath/ventral surface of the cephalad lamina).

    - At this point, carefully enter the epidural space/spinal canal (there are a variety of ways to do this, but all involve taking down an aspect of the ligamentum flavum). At L5–S1, you often do not need to remove any lamina.
    - At more cephalad levels, you often need to perform a small laminotomy to create room to safely work within the epidural space.
  - Diskectomy:
    - It is extremely important to identify the lateral aspect of the dural sac and traversing nerve root.
    - Carefully mobilize the traversing nerve root (S1 for a L5–S1 microdiscectomy) and retract it medially.
    - Then, look for the disk herniation.
    - If there is no tear in the annulus, use a 15-blade scalpel and incision a small area of the annulus.
    - Then use a pituitary rongeur to remove the herniated fragments.
    - You do not need to remove the entire disk.
  - Wound closure:
    - Close the fascia, subcutaneous tissue, and skin in layered fashion.
    - Be sure to have excellent hemostasis prior to closure.
    - If there is any concern for an iatrogenic dural tear, ask the anesthesiologist to hold a Valsalva maneuver.

Spinal Stenosis

- Lumbar laminectomy:
  - In general, a lumbar laminectomy or decompression is the treatment of choice for spinal stenosis with resultant neurogenic claudication.

    - There are several ways to accomplish an adequate decompression (traditional laminectomy, bilateral laminotomies with or without foraminotomies, microdecompression, etc.).
  - The positioning and surgical exposure are similar to that of a microdiskectomy.
    - However, for a laminectomy, you need to expose the lamina on the right and left sides of the spinous process.
    - Exposure should be carried out to the pars interarticularis, but do not violate the facet capsules.
    - Carefully enter the epidural space, and use a combination of kerrison rongeurs to remove the lamina (the amount of bone removed is dictated by the location and severity of the stenosis).
    - In general, be sure to adequately decompress the central canal, lateral recess (subarticular stenosis), and neural foramina.

Complications

- Potential complications include one or more of the following:
  - postoperative epidural hematoma
  - nerve root injury
  - radiculitis
  - recurrent disk herniation
  - infection (discitis, epidural abscess, osteomyelitis)
  - iatrogenic instability (pars fracture, facet violation, etc.).

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ADULT KYPHOSIS AND SCOLIOSIS

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Anatomy and Pathoanatomy

Adult spinal deformity, as defined by the Scoliosis Research Society, can be of any etiology in a skeletally mature individual. Scoliosis is a coronal plane deformity greater than 10 degrees off a vertical line drawn from the center of the pelvis (center sacral vertical line/axis). Two main types are described: (1) Adult idiopathic scoliosis (existed in childhood or adolescence and has continued); (2) Adult degenerative or "de novo" scoliosis (developed in adulthood). The latter arises from degenerative disc disease and the subsequent asymmetrical narrowing of disc height along with vertebral body rotation or translation due to resulting instability.

Kyphosis is a sagittal plane deformity due to failed arthrodesis, trauma, ankylosing spondylitis, congenital kyphosis, Scheuermann disease, compression fractures, infection or neoplasm, and other less common etiologies. Scoliosis and kyphosis are often concomitant pathologies. These factors, along with hypertrophied ligamentum flavum and facet joint overgrowth, can result in stenosis, leading to the symptoms of neurogenic claudication or radiculopathy. Radicular pain can often be attributed to narrowing of the neural foramen on the concavity of the curve in the upper lumbar levels. This produces anterior thigh and leg pain. Posterior leg pain that extends to the foot is produced by the traction on nerve roots on the convexity of the curve at the lower lumbar levels. Adult spinal deformity exists along a radiographic spectrum from mild to severe and may be stable or progressive. Symptomatology and outcomes of treatment have not been proven to be associated with the severity of the deformity, and each patient must be evaluated and treated in an individualized manner.

Clinical History

- Most patients with kyphosis or scoliosis present with back pain.
- Other presenting symptoms often include leg pain, numbness, tingling, or cramping. In some cases, weakness is also present.
- Overall, the clinical presentation is most typically consistent with that of lumbar stenosis, back pain, and subsequent decline in function.
- Patients may have transient pain relief when leaning over an object with a flexed spine, have pain after a specified distance when walking, and feel better when resting or laying supine.
- In patients over 40 yrs of age, pain is commonly associated with radicular pain and neurogenic claudication.
  - In contrast, patients under the age of 40 with adult scoliosis present with primarily back pain.
  - Curve magnitudes less than 40 degrees have a low probability of progression to greater than 40 degrees.
  - Risk factors related to curve progression include
    - Cobb angle >30 degrees
    - apical rotation greater than Nash–Moe II
    - lateral listhesis >6 mm
    - intercrestal line through or below L4/5 disc space (Pritchett)

Differential Diagnosis

- The etiology of the pain and deformity is important to determine.
- Most often, either degenerative changes or pre-existing (childhood) deformity in the spine are responsible.
- However, other etiologies must be considered, particularly in an

elderly population.

- These include tumor (most likely metastatic)
  - Infection
  - minor trauma (particularly osteoporotic compression fractures)
  - prior surgery resulting in deformity (flat back syndrome)
  - pseudarthrosis
  - spondylolisthesis
  - ankylosing spondylitis and surrounding major joint degeneration or contracture (hips, knees, shoulders).
- The treatment plan will depend significantly on the etiology.

Physical Exam

- A complete spine-related exam is essential, including assessment of:
  - overall physical condition
  - localization of pain
  - sagittal and coronal balance upon standing
  - obliquity of the pelvis and shoulders
  - flexibility of the spinal deformity
  - limb length discrepancy
  - hip and knee flexion contractures
  - skin condition at potential surgical sites
- A complete neurologic exam includes evaluation of:
  - gait
  - balance
  - strength in individual myotomes
  - sensation (pin prick)
  - proprioception
  - reflexes (including abdominal wall)

- upper motor neuron signs
- muscle tone/spasticity.

- Lower extremity joint contractures and pain with range of motion must be evaluated.
  - A change in deformity from standing to seated position may be due to lower extremity contractures or limb length discrepancy.

IMAGING

- **Plain Radiographs:**
  - Standing 36-in PA and lateral spine films are essential in diagnosis by providing a global evaluation of the deformity.
  - X-rays are necessary for monitoring of deformity progression and treatment planning.
  - In order to observe the full magnitude of the spinal deformity, the patient's knees must be fully extended, with assistance if necessary.
    - Focused views of cervical, thoracic, lumbar, or lumbo-sacral regions may be obtained.
    - Deformities are further characterized by flexion, extension, lateral bending, &and traction views to assess a curve's flexibility or rigidity.
  - An x-ray affords an estimated qualitative assessment of bone density.
    - Whenever possible, imaging should be done in a weight-bearing posture (standing if possible), to allow for analysis of the deformity in its fullest extent and in the likely most painful position.
  - Assessment of not only coronal, but sagittal balance is essential by drawing the center-sacral line, and C7 plum line.
  - Evaluation of pelvic and shoulder obliquity is useful for surgical planning.
    - An understanding pelvic parameters (pelvic incidence, sacral

slope, and pelvic tilt) will define the severity of the deformity and help guide surgical correction.

- A limited evaluation of the hip joints should be part of a PA spine x-ray, while further lower extremity imaging is obtained when indicated.

- **MRI:**
  - Supine, noncontrast magnetic resonance imaging allows assessment of neurologic elements &and compression thereof both in the central canal as well as the lateral recess and foramina, especially in patients who have had prior decompressive surgery.
  - An MRI affords more detailed analysis of joint degeneration, disk quality, and surrounding soft tissues.
  - A more detailed view of tissue abnormalities, including tumors, is possible.
  - An MRI scan is most useful in minor deformity, as the image moves in and out of plane with greater deformities.
  - Sagittal and coronal reconstructions are essential.
  - The best images are obtained when the gantry alignment is coaxial with the plane of the deformity.
- **CT:**
  - Computed tomography is used for a more detailed exam of the bony anatomy and degenerative bony changes.
  - In addition, instrumentation selection can depend on pedicle size, and prior surgical bony changes, such as decompressive laminotomies/laminectomies, which are more easily identified.
- **CT Myelogram:**
  - Injection of intrathecal radio-opaque dye prior to CT scanning allows for evaluation of neurologic elements in patients who are unable to undergo MRI scanning (pacemaker/defibrillator, spinal cord/deep brain stimulator, etc.).
  - A CT scan is perhaps less susceptible to implant artifact than an MRI.
  - CT myelogram imaging is useful in assessing canal stenosis with

deformity of greater magnitude.

  - Image reconstruction in the sagittal and coronal plane are essential.

- **Other Imaging:**
  - Bone scans are generally not helpful in treatment planning for deformity, but are a useful tool to screen for focal pathology such as infection or tumor if suspected.
  - Bone density evaluation by DEXA scanning is at times necessary as pre-operative optimization of bone density can decrease implant-related complications (such as fractures, screw/hook pull-out) and allow for surgical planning (i.e., use of cemented pedicle screws).

Prevention

- There are currently no clinically proven methods for prevention of adult scoliosis caused by pre-existing childhood deformity or degenerative changes.
- Bracing in childhood scoliosis may decrease the magnitude of deformity at skeletal maturity and therefore help prevent or delay clinical deterioration in adulthood.
- Medical treatment and prevention of osteoporosis can decrease the incidence of compression fractures and resulting deformity.

Nonoperative Management

- Nonsurgical means of pain control and physical conditioning should be the mainstay of treatment exhausted prior to surgical consideration in the absence of progressive spinal deformity or neurologic compromise.
- Modalities include physical therapy and pain management.
- Medical management includes non-narcotic pain medications and anti-inflammatory drugs.
  - NSAIDS and other over-the-counter medications should be utilized.
  - Epidural steroid injections can be used periodically for radicular

pain or symptoms related to neurogenic claudication.
  - Facet joint blocks and sacroiliac injections may alleviate axial back pain.
  - Trigger point injections may help treat enthesitis and muscular pain.
  - Non-sedating muscle relaxants can be used during periods of pain exacerbation.
- The treatment of chronic pain is best managed by the primary care provider or a pain management clinician.
  - Use of orthoses is often not well tolerated in the elderly and has not been shown to alleviate pain or deformity progression, however, may be used in individual circumstances.

Operative Indications

- Failure of nonoperative management with resultant intractable pain or deterioration of function
- Deformity progression (sagittal and/or coronal plane imbalance)
- Neurologic deterioration
- Impending deformity or neurologic compromise (i.e., expected fracture due to tumor)

Surgical Treatment

- Pre-operative planning is essential.
  - Adult scoliosis surgery is complex from a technical, anesthetic, medical, and postoperative management perspective.
  - It should only be performed by surgeons who commonly encounter these patients.
  - Peri-operative care requires a team approach, and complications should be anticipated at every step.
  - Evolving evidence suggests that physically deconditioned patients may recover more quickly from staged operations (i.e., exposure,

instrumentation first, and delayed deformity correction and fusion at a later date).

- Pre-op Area:
  - Take a history and repeat physical exam prior to performing surgery.
  - Delineate if radiculopathy is unilateral and which leg is more symptomatic.
  - Be aware of anesthesia plan and antibiotics.
  - Obtain consent and mark operative site.
- Positioning:
  - Most commonly, the patient is positioned prone, with less common positions including supine or lateral decubitus, depending on the surgical approach to the spine.
  - As patients are often elderly, with perhaps a less than optimal nutritional status, and also have deformity, careful attention must be given to protection of the skin at bony prominences.
  - The belly should hang freely in the prone position to minimize resistance to venous return, which can increase spinal bleeding.
  - Prolonged facial pressure can be avoided by use of Gardner-Wells tongues or Mayfield holders.
  - Traction is used to partially correct deformity.
    - Arms and legs must be positioned to avoid nerve pressure or stretch, while allowing anesthesia access, and without restriction to flow or use of venous or arterial lines.
- **Localization:**
  - After exposure of the spine, an intra-operative x-ray is essential to determine the spinal level.
    - This avoids the performance of incorrect-level surgery.
  - A level presumed to be included in the operation is marked by various means, all of which include the use of a radio-opaque object.
    - Sponges, other instruments, retractors, and cables/wires/tubing outside of the wound should be moved so as not to interfere

with image interpretation.

- **Approach:**
  - There are many approaches to the spine, and their use depends on the deformity and surgical plan.
  - In general, anterior approaches require the assistance of a vascular or chest surgeon and give access to the anterior vertebral bodies and the disc spaces.
  - Anterior approaches can include thoracotomy or abdominal exposure in a transperitoneal or retroperitoneal plane.
  - Posterior approaches utilize the periosteal stripping of musculature to gain access to the posterior elements of the spine and disc space if needed.
- **Anesthesia care:**
  - Intra-operative spinal cord monitoring requires the use of noninhalational, nonparalytic, total-intravenous-anesthesia (TIVA).
  - Blood loss can be extensive, particularly during the performance of osteotomies, and intra-operative transfusion of packed red blood cells, platelets, fresh frozen plasma, and colloid must be expected.
  - Prolonged surgeries may require redosing of antibiotics, continued ventilatory support post-operatively, and monitoring in an intensive care unit.
- **Spinal Cord Monitoring:**
  - The spinal cord's integrity can be monitored under TIVA.
  - Somatosensory-evoked potentials (SSEPs), EMG, and motor-evoked potentials (MEPs) are commonly observed by a technician or neurologist.
  - Some controversy exists as to the cost-effectiveness and usefulness of spinal cord monitoring.
    - If there is a change in the monitored signal beyond a certain threshold, the surgeon is notified by the monitoring technician.
    - Then a series of steps is initiated that may include a review of anesthetics administered, blood levels (hemoglobin), mean

arterial pressure, core temperature, and reversal of recent deformity corrective steps.

- The gold standard of intra-operative neurologic status assessment remains the Stagnara wake-up test.

- **Fusion techniques:**
  - Fusion surgeries can be performed with or without instrumentation, which consists most commonly of pedicle screws and hooks.
    - Instrumentation serves to stabilize the spine until fusion occurs, which was previously accomplished with prolonged postoperative bracing.
      - Posterolateral fusion (PSF) between the transverse processes of the vertebral bodies remains the gold standard.
      - Posterior fusion along the laminae is also performed.
      - In many instances anterior column support through either anterior interbody fusion (ALIF), posterolateral interbody fusion (PLIF), far lateral or transforaminal interbody fusion (TLIF) can be helpful to ensure adequate support and bony fusion, as well as contribute to deformity correction.
      - Bone grafting can be autologous from iliac crest or local bone removed during decompression, or allograft.
      - Autologous iliac crest remains the most osteogenic graft available.
      - Various biologic substitutes are in use to stimulate fusion, but can add significant expense to operation.

Postoperative Rehab and Expectations

- **Most important:** Recovery from adult scoliosis surgery is lengthy and difficult.
- A detailed discussion must be held with every surgical candidate about the rehabilitation process.
  - In general, the pace and extent of convalescence is dependent on the patient's preoperative physical status.

- Most patients are discharged to a rehabilitation facility prior to returning home.
  - It is of utmost importance to stress the following, as both can interfere with fusion:
    - smoking cessation both pre- and postoperatively
    - the use of non-NSAID pain medications in the initial postoperative period.
      - Close follow-up in the early postoperative period is essential, with longer interval clinic visits later on.

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SPINAL INFECTIONS

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Introduction

Historically, infections of the spine have caused significant morbidity and mortality. However, as antibiotics and surgical techniques have evolved, the results of treating spinal infections have significantly improved.

- Spinal infections can be broken down into three major categories:
  - pyogenic infections
  - granulomatous infections
  - epidural abscesses
- It can also be useful to classify the infection as
  - acute (< 3 wks)
  - subacute (3 wks–3 mo)
  - chronic (> 3 mo)
- The presentation and treatment algorithm will often differ significantly for the different types of infections.

Pyogenic Vertebral Osteomyelitis

Epidemiology and Etiology

- Vertebral body osteomyelitis represents 2–7% of all cases of osteomyelitis.
- Risk factors include
  - patients greater than 60 yrs of age

- males
- intravenous drug users
- immunocompromised patients such as patients with diabetes, HIV, or patients who are taking corticosteroids

- The most common location for pyogenic vertebral osteomyelitis is the lumbar spine, and the most common causative organism is *Staphylococcus aureus*.
  - While *S. aureus* accounts for 36–55% of the cases, in one series of over 100 cases, 37% were caused by traditionally low virulence organisms.
- Vertebral body osteomyelitis can arise from local extension into the bone (i.e., from a psoas or intra-abdominal abscess), from hematogenous spread, and/or from extension through the endplate as a consequence of discitis.

Clinical Presentation

- The most common symptom at initial presentation is neck or back pain, which is present in up to 92% of patients.
  - While the pain is often severe, other characteristics of the pain include:
    - pain accompanied by paraspinal spasms
    - pain at rest that is not related to activity
    - night pain that wakes the patient from sleep
  - While back and/or neck pain is the most common symptom, about 15% of patients present with atypical pain including chest or abdominal pain.
- Other symptoms may include weakness, weight loss, and fever.
  - It is important to know that fever is only present in approximately 50% of patients and is often absent in indolent infections.
- Clinical presentation will also vary, based on the location of the infection, host factors, and the virulence of the pathogen.
- Patients with lumbar infections often present with a positive straight-leg raise, difficulty bearing weight, psoas and hamstring irritation, and a loss of lumbar lordosis.

- Cervical spine infections may present with torticollis.
- Approximately 17–25% of patients will present with a neurologic deficit due to either cord compression or root impingement.
- The time to diagnosis varies in the literature, but, in a recent study, the average time from initial symptoms to diagnosis was 1.8 mo.

Differential Diagnosis

- Initial evaluation should consist of both
  - AP and lateral radiographs
  - Lab tests, including
    - erythrocyte sedimentation rate (ESR)
    - complete blood count (CBC)
    - C-reactive protein (CRP). (see below)
- The differential diagnosis should always include metastatic disease.
  - Therefore, tissue should be sent to pathology, as well as microbiology.

Imaging

- Initial evaluation should consist of AP and lateral radiographs
- The earliest and most consistent radiographic finding is disc space narrowing, but it may be absent in over 20% of patients upon presentation.
  - Usually, after 3–6 wks, destructive lytic lesions in the anterior vertebral body and endplates can be seen.
  - Later signs that may be present include sclerosis and a loss of normal alignment.
- Historically, radionucleotide studies were used to aid in early diagnosis, but now magnetic resonance imaging (MRI) with contrast has become the imaging modality of choice.
  - MRI has a sensitivity of 96% and specificity of 92% in identifying vertebral osteomyelitis.
  - Importantly, MRI also can help differentiate between pyogenic osteomyelitis and granulomatous osteomyelitis.

Lab Studies

- Initial evaluation should consist of lab tests, including
  - erythrocyte sedimentation rate (ESR)
  - complete blood count (CBC)
  - C-reactive protein (CRP). (see below)
    - The ESR is elevated in almost all patients; however, the white blood cell (WBC) count may only be elevated in 30% of patients.
- Once the lesion has been identified, a biopsy is needed to guide treatment.
  - Antibiotics should be held until a biopsy is obtained.
  - A CT-guided biopsy will be able to determine the pathogen in approximately 70% of cases.
  - It is important to send the specimen for
    - Gram stain
    - Acid-fast stain
    - Aerobic, anaerobic, fungal, and TB cultures.
  - Bacterial cultures should be maintained for 10 d to detect low-virulence organisms

Treatment

- Once the pathogen has been identified, antibiotic treatment can be tailored to the specific organism.
  - Patients should be treated with at least 4 wks of IV antibiotics followed by a course of oral antibiotics.
  - Treatment with less than 4 wks of IV antibiotics has led to high failure rates.
  - An infectious disease consult should be obtained to help tailor the type and duration of antibiotic treatment.
  - Oral pain medicines and bracing may be used to help alleviate the pain.
- While most patients are treated without surgery, *surgical indications*

include:

- inconclusive closed biopsy
- an abscess leading to systemic illness
- failure of prolonged nonoperative treatment
- a neurologic deficit due to spinal cord or cauda equina compression
- significant deformity or instability of the spine

- Upright/standing x-rays should be obtained on all patients to rule out instability.
  - Importantly, lumbar nerve root impingement is not an indication to operate, as the treatment results are often similar with or without operative intervention.
- Multiple surgical approaches are possible, but an anterior approach often allows for the most thorough debridement.
- Unlike other orthopedic infections, hardware is often used in spinal infections.
  - A titanium cage with allograft and/or posterior instrumentation has been shown to be safe in the setting of a spinal infection; neither increases the risk of a chronic infection.

Granulomatous Infections

Epidemiology and Etiology

- Granulomatous infections of the spine are most often caused by tuberculosis; however, fungi, spirochetes, and other bacteria may also cause this condition.
- The World Health Organization (WHO) estimates there are over 800,000 worldwide cases of tuberculous spondylitis, also known as Pott disease.
- Approximately 1–2% of tuberculosis cases develop skeletal involvement, and 50% of these cases will involve the spine.
- Risk factors for tuberculous spondylitis include patients
  - with a family member with tuberculosis,

  - who visit homeless shelters or prisons,
  - from South-East Asia or South America.

Clinical History

- Compared to patients with pyogenic vertebral osteomyelitis, patients with tuberculous spondylitis often have a chronic and indolent presentation.
- Pain is the most common presentation, and it is often located in the thoracic spine.
- Patients with tuberculous spondylitis commonly present with night sweats, malaise, and weight loss.

Lab Workup

- The workup for tuberculous spondylitis is the same as for pyogenic osteomyelitis.
- However, it is not uncommon to have a normal WBC and ESR in tuberculosis.
- In addition, the Mantoux test, the tuberculosis skin test, can be beneficial.
- Importantly, this test can be falsely negative in immunocompromised patients.
- If a clinician has a high suspicion for tuberculosis, PCR tests can be done on the biopsy sample to quickly identify resistant organisms.

Imaging

- All patients warrant radiographs, an MRI with contrast and a biopsy.

Treatment

- Once a definitive diagnosis of tuberculous spondylitis has been established, treatment is primarily medical.
- Different combinations of medications have been used, including
  - Isoniazid
  - Rifampin
  - pyrazinamide

  - ethambutol
  - Treatment length is often 6 mo or more.
- Patients tend to have significant improvement of pain and neurologic symptoms with an appropriate course of medication.
- Surgical intervention is limited to patients with
  - spinal instability
  - severe deformity
  - myelopathy
  - severe sepsis
  - clinically significant abscesses or an open draining sinus.
- The surgical approach is based off of the location of the lesion.

Epidural Abscess

Epidemiology and Etiology

- Epidural abscesses rarely occur in isolation and are usually a sequelae of vertebral body osteomyelitis.
- About 7% of pyogenic spinal osteomyelitis will lead to the development of an epidural abscess.
- Risk factors include
  - diabetes mellitus
  - trauma
  - intravenous drug use
  - alcoholism
  - epidural injection
  - spinal surgery
- *S. aureus* is the most common pathogen.

Patient Presentation

- The most common symptoms are pain and fever, but neurologic symptoms are much more common with an epidural abscess than in pyogenic osteomyelitis or tuberculous spondylitis.

- In a large meta-analysis of over 900 cases
  - 20% of patients presented with radicular pain
  - 26% had weakness
  - 24% had bowel or bladder incontinence.
- A timely and accurate diagnosis is incredibly important, as a patient with an epidural abscess can have rapid progression of neurologic symptoms.
- Thirty-one percent of patients in the aforementioned review developed paraparesis or paraplegia.

Radiographic and Lab Workup

- The work up for an epidural abscess is similar to other infections of the spine.
- However, many of these patients present with neurologic symptoms.
- Because of the high risk of progressive neurologic deficits, an MRI with Gadolinium contrast should be done urgently.

Treatment

- Unlike other spine infections, the treatment for an epidural abscess is almost always surgical drainage.
- Similar to other infections, the location of the lesion will dictate the surgical approach.
- Patients who may be treated without surgery include patients
  - without a neurologic deficit
  - who are not expected to survive surgery, or if paralysis has been present for more than 48 hrs so that neurologic improvement is doubtful.
- These patients should be treated with IV antibiotics similar to pyogenic osteomyelitis.

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INTRODUCTION TO TUMOR/INITIAL WORKUP

JAMES M. SAUCEDO

Clinical History

- Patients may present in a myriad of ways.
  - Some patients may report worsening pain, pain at night or at rest, pain that started initially with an injury but did not improve, or even a chronic, nagging pain.
  - Others may present with masses (with or without pain) or with imaging positive for an "incidental finding."
  - Patients may also present with a fracture that occurred secondary to a low energy mechanism.
- When approaching the initial work up of musculoskeletal tumors, one must consider the patient's
  - age (some primary musculoskeletal tumors occur with higher frequency in certain age groups)
  - personal history of cancer or systemic disease (some primary cancers have high predilection for skeletal metastasis while other conditions, such as Paget disease, may predispose patients to certain sarcomas)
  - rate of progression of symptoms (a slow growing mass suggests a less aggressive process, whereas a fast growing mass may portend a worse diagnosis).

Physical Exam

- The exam may start with the involved extremity but should always include a full survey of the patient.
- When palpating the soft tissue masses, one should determine the character of the mass:
  - Is it mobile or fixed?
  - Is it soft or firm?
  - Is it warm or pulsatile, which may suggest a hyper-vascularized tumor?
- One should also assess for tumors at other sites as well as for enlarged lymph nodes.
- As some masses and/or bony lesions may represent metastatic disease, it is also important to examine potential sites of primary disease (e.g., breast exam in females, prostate exam in men).
- Finally, one must also perform a careful neurologic exam to rule out any neurologic compromise (some tumors have a predilection for the spine).

Laboratory Workup

- Laboratory studies should include
  - CBC with differential (e.g., may be abnormal with such conditions as lymphoma or multiple myeloma)
  - complete chemistry, including albumin and alkaline phosphatase (e.g., elevated alkaline phosphatase suggests increased bone turnover)
  - ESR and CRP (e.g., abnormal values may suggest an infectious or otherwise inflammatory condition)
  - serum protein electrophoresis and urine protein electrophoresis (i.e., multiple myeloma).

Imaging

- Imaging should always begin with plain x-rays with orthogonal views of the lesion.

- For lesions involving long bones, it is important to obtain films of the full bone to look for skip lesions (e.g., in addition to obtaining knee x-rays for a lesion involving the distal femur, one should also obtain an image of the entire femur).

- When evaluating a bone lesion, one must characterize the nature of the lesion and attempt to determine the aggressiveness of that lesion.
  - To this end, Enneking suggested that we ask four questions:
    1. Where is the lesion (i.e., epiphyseal vs. diaphyseal; eccentric vs. central; etc.)?
    2. What is the lesion doing to the bone (i.e., radiolucency suggests a lytic process, whereas radio-opacity suggests a blastic process)?
    3. What is the bone doing to the lesion (i.e., is there periosteal reaction? Does the lesion have well- or ill-defined borders?)?
    4. What is the nature of the lesion (e.g., based on the previous questions, does this appear to be a benign or aggressive process? Are there any clues to its nature?)?
       - Asking and answering these questions can help in narrowing the differential diagnosis.
         - E.g., certain neoplastic processes have characteristic radiographic appearances and will tend to occur in certain locations.

- To better characterize the lesion, one may consider 3D imaging, such as CT or MRI.
  - CT is useful for looking at mineralization within tumors (e.g., enchondroma) and determining the degree of cortical involvement (particularly if one is concerned about an impending fracture).
  - MRI is especially useful for characterizing soft-tissue masses, extra-medullary extension of primarily osseous tumors, evaluating long bones for skip lesions, and to better assess pelvic and spinal tumors.

- Bone scintigraphy can be useful for further evaluating suspicious lesions found on x-ray as well as detecting remote sites of metastasis; however, this study is best for detecting osteoblastic activity and may miss such processes as multiple myeloma.

- If there is concern for a more widespread process such as multiple myeloma, a skeletal survey can help determine the extent of disease.
  - In addition, one should also consider obtaining CT scans of the chest, abdomen, and pelvis to evaluate for primary sites of disease or distant sites of metastasis.

Principles Of Biopsy

- Not all lesions require biopsy.
  - Lesions that appear benign and have classic characteristics on exam and imaging studies (e.g., lipomas or unicameral bone cysts) may be observed as long as the patient remains asymptomatic and the lesion does not appear to be growing.
  - One should consider biopsy for lesions that are large, deep, growing in size, or cause pain.
- There are three types of biopsy: fine needle aspiration, core needle biopsy, and open biopsy.
  - Fine needle aspiration (looking at individual cells), requires an experienced cytopathologist to make a definitive diagnosis and is probably the least diagnostic.
  - Core needle biopsy is most commonly used in practice today.
    - The main advantage is that it is less invasive, but its utility is limited by potential sampling error.
  - Open biopsy remains the gold standard for most lesions.
    - Open biopsy includes incisional biopsy, (marginal) excisional biopsy, or primary wide excision.
- One may consider incisional biopsy for lesions greater than 3–4 cm and in areas where the surrounding structures are at high risk for contamination.

- This involves incising into the lesion directly without taking out the entire lesion.

- An alternative to incisional biopsy is excisional biopsy, in which the entire lesion is removed.
  - It is considered a marginal excision unless a cuff of normal tissue is taken with the biopsy.
  - The advantage is that a large sample size allows for more accuracy, and if this is a benign lesion, the treatment is accomplished at time of biopsy.
  - However, if the biopsy is not done carefully, there can be significant contamination of the surrounding tissue and insufficient margins, which increase the risk for normal soft tissue sacrifice at the time of definitive surgery if the lesion turns out to be malignant.
- Primary wide excision should be considered for lesions that are highly suspected of being malignant and involves excising the lesion with a cuff of normal tissue.
  - This approach must be carefully considered, as there may be significant morbidity associated with this type of biopsy.
  - The risks of a potentially malignant lesion must outweigh the functional and cosmetic consequences of a wide excisional biopsy.
- Principles of successful biopsy include:
  - making incisions that would not preclude future, potential reconstructive, or salvage procedures
  - using longitudinal incisions
  - keeping instruments, gloves, and sponges used near the tumor field in a separate basin
  - if doing another procedure on the same patient, the patient and team should re-drape and re-scrub, and new instruments should be used
  - if a tourniquet is used, the limb should not be exsanguinated
  - the most direct approach to the lesion should be made and should go through compartments rather than between them to avoid

contamination of those other compartments

- flaps should be avoided
- meticulous hemostasis should be ensured throughout the case
- finally, if there is concern for potential post-operative hematoma, a drain should be used and placed close to the surgical wound in line with the surgical incision.

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METASTATIC DISEASE

BRIAN CHILELLI

Introduction

Metastatic bone disease is common and may significantly affect a patient's quality of life. Following lung and liver, bone is the most common site for metastasis. Cancers most likely to metastasize to bone include breast, lung, thyroid, kidney, and prostate. Frequent sites of metastasis include the axial skeleton and proximal long bones of the upper and lower extremities. Patients with metastatic disease will often present with pain. Age is an important factor when evaluating for metastatic bone disease. Metastatic carcinoma is the most common diagnosis of a destructive bone lesion in a patient over the age of 40.

Clinical History and Physical Exam

- Pain is the most common presenting symptom in a patient with metastatic disease to bone.
- They should be assessed
  - for any constitutional symptoms such as fatigue, changes in appetite, or loss of weight.
  - it is also important to ask about any personal or family history of cancer.
- A thorough family history of cancers should also be obtained.
- The physical exam is also very important and should focus on evaluating for
  - swelling/edema

- skin changes
- soft tissue masses
- range of motion
- crepitus
- pain
- complete neurologic exam

Lab Studies

- The workup of a patient with suspected metastatic disease to bone should aim at identifying the primary tumor site as well as determining the local and distant extent of disease.
- Lab studies that may be helpful include
  - CBC
  - full chemistry panel
  - alkaline phosphatase
  - ESR
  - CRP
  - A serum and urine electrophoresis may provide additional information when evaluating for multiple myeloma.

Imaging

- A CT of the chest, abdomen, and pelvis will aid in identifying the primary tumor site.
- Bone scans are helpful in identifying additional sites of bone metastasis but may be falsely negative in patients with multiple myeloma or renal cell carcinoma.
- Finally, radiographs should be taken of the entire bone involved.
  - Radiographs should be scrutinized for evidence of:
    - pathologic fracture

    - the amount of cortical destruction
    - the location of the lesion
    - the appearance of the bone involved (lytic, blastic, or mixed).
- CT scans and/or MRI of the affected bone are not always necessary but may be useful for preoperative planning in select cases.

Differential Diagnosis

- As mentioned, metastatic bone disease is the most common diagnosis in an adult over the age of 40 with a destructive bone lesion.
- However, other possibilities include multiple myeloma, lymphoma, primary bone tumors, osteomyelitis, or other non-neoplastic bone conditions.

When to Biopsy

- The primary tumor can be identified in 85% of cases by collectively using history, physical exam, lab studies, radiographs, bone scans, and CT scans of the chest, abdomen, and pelvis.
- A biopsy is usually obtained for diagnosis either intraoperatively with frozen sections or preoperatively when there is no identifiable primary tumor.
- Stabilizing a presumed bone metastasis may be limb threatening if the underlying diagnosis is truly a malignant primary bone tumor.
- Types of biopsies include fine needle aspiration, core biopsy, and open incisional biopsy.
- Regardless of the type of biopsy, proper oncologic principles should be followed when performing the procedure.

Treatment

- The goals of treatment are to decrease pain, improve function, and to prevent pathologic fracture.
- The treatment requires a multidisciplinary approach and includes

- orthopaedic surgeons
- general practitioners
- oncologists
- radiation oncologists
- radiologists
- physical medicine rehabilitation doctors

Nonoperative Management

- Nonsurgical and surgical treatment options exist depending on the scenario.
- Nonsurgical options include
  - analgesics
  - protected weight bearing
  - splinting
  - chemotherapy
  - hormone therapy
  - external beam irradiation
  - radioactive isotopes
  - bisphosphonates

Operative Indications

- When surgery is indicated the type of fixation used depends on the location of the lesion, diagnosis, and prognosis.
- Various scoring systems have been described in order to predict the risk of pathologic fracture.
  - The Mirels scoring system was developed to serve as a guide to orthopaedic surgeons on surgical decision making for impending pathologic fractures.
    - The scoring system involves assessing 4 variables:

        - location of the lesion
        - pattern of bone destruction
        - size of the lesion
        - associated pain
    - Each variable is scored from 1–3 and added for a total combined score, which correlates with risk of pathologic fracture.
        - Prophylactic fixation is recommended for scores >8 and should be considered for scores of 8.
        - However, there are subjective variations when using this scoring system and therefore it is best used as a guide in conjunction with clinical judgment.
- **Humerus:**
    - Symptomatic lesions at low risk for pathologic fracture can be treated nonsurgically with external beam radiation.
    - Lesions at high risk for pathologic fracture should be treated with intramedullary nailing.
    - Pathologic humerus fractures tend not to heal well and may cause significant pain and therefore intramedullary nailing should be considered.
    - Plate fixation is acceptable if adequate screw purchase can be obtained but is unable to prophylactically stabilize the entire humerus.
    - Methylmethacrylate can be used to increase screw purchase and fixation strength.
    - Proximal humerus endoprosthesis is also an option for proximal humerus pathologic fractures with significant bone loss.
- **Femur:**
    - Symptomatic lesions at low risk for pathologic fracture can be treated nonsurgically with external beam radiation.
    - Lesions at high risk for pathologic fracture should be treated with internal fixation and depending on the site of disease a long cephalomedullary device that spans the entire bone is preferable.
    - Options for intertrochanteric fractures include

    - cephalomedullary nails
    - calcar replacement arthroplasty
    - extramedullary side plate and hip screw constructs with or without methylmethacrylate.
  - Pathologic fractures and impending fractures of the femoral head and neck should be treated with replacement arthroplasty.
- **Spine:**
  - Radiation may be used to treat pain when no mechanical compromise is present.
  - Vertebroplasty and kyphoplasty are also options to provide pain relief in pathologic compression fractures without instability.
  - Surgery is indicated for instability or advanced disease resulting in worsening neurologic compromise.
    - The goals of surgery are to
      - decompress neural structures
      - provide stability
      - correct deformity
      - decrease pain
  - In the lower cervical spine (C3–C7), anterior corpectomy and reconstruction with methylmethacrylate can be performed when 1 or 2 levels are involved.
  - Posterior decompression and instrumentation may be required for advanced disease extending over several levels.
  - Management of C2 involvement depends on the amount of instability, destruction, and neurologic involvement.
  - Treatment varies between radiation and immobilization with cervical orthosis to posterior fusion and/or anterior decompression.
  - The vertebral body is the most common site of involvement in the thoracic and lumbar spine.
    - Therefore an anterior decompression and fusion is frequently performed for 1- or 2-level disease.

- If more than 2 levels are involved, additional posterior stabilization should be performed to increase mechanical stability.
- Combined anterior and posterior decompression may be necessary for circumferential disease.

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BONE TUMORS

BRIAN M. WEATHERFORD

Benign Bone Tumors

Osteoid Osteoma

Epidemiology

- These lesions can occur at all ages, but most common in young patients between the ages 5 and 30 yrs.

Clinical History

- Patients present with increasing pain and may have night pain.
- Classically, the pain is relieved with NSAIDs as osteoid osteomas produce prostaglandins.
- The pain may be referred to an adjacent joint when the lesion is intracapsular.
- The tumor may cause painful scoliosis, growth disturbance, and flexion contracture.
  - Common locations include the
    - proximal femur
    - tibial diaphysis
    - posterior elements of the spine

Differential Diagnosis

- Osteoblastoma
- Osteomyelitis
- Stress fracture

Imaging

- XR:
  - Intensely reactive or sclerotic bone surrounding a radiolucent nidus.
  - The nidus must be less than 1.5 cm; otherwise the lesion likely represents osteoblastoma.
- CT:
  - Imaging modality of choice if not seen on plain films.
  - CT scan provides better contrast between the nidus and surrounding reactive bone than MRI.

Histology

- There is a distinct separation between the nidus and the surrounding reactive bone.
- The nidus appears as an interlacing network of osteoid trabeculae with variable mineralization.
- The trabecular pattern is disorganized and the greatest mineralization is in the center of the lesion.

Management

- Patients may be managed nonoperatively with NSAIDs as these are benign, self-limiting lesions.
- Approximately 50% of patients will require no further intervention and the symptoms eventually resolve over 2–3 yrs, once the lesion burns out.
- If intervention is chosen then options consist of CT-guided radiofrequency ablation (RFA) or open excision.
  - RFA is the most common form of treatment and approximately 90% of patients are successfully treated with this procedure.
  - Open surgical excision may be indicated when the lesion is next to critical structures, such as osteoid osteomas found in the posterior elements of the spine.

Osteoblastoma

Epidemiology

- These lesions can occur at all ages, but, similar to osteoid osteomas, most common in young patients between the ages 5 and 30 yrs.

Clinical History

- Patients present with increasing pain and may have night pain.
- Unlike osteoid osteoma, the pain is not relieved with NSAIDs and neurologic symptoms may be present as the mass grows.
- The tumor may cause painful scoliosis, growth disturbance, and flexion contracture.
- The most common location is the posterior elements of the spine or sacrum; however, lesions may also occur in the proximal humerus and hip.

Differential Diagnosis

- Osteoid osteoma
- Osteomyelitis
- Osteosarcoma

Imaging

- XR:
  - Bone destruction, possibly without the reactive bone seen in osteoid osteoma.
  - The bone destruction may have a "moth-eaten" appearance similar to a malignant or metastatic lesion.
  - The radiolucent nidus should be greater than 2 cm.

Histology

- There is a distinct separation between the nidus and the surrounding reactive bone.
- The nidus shows immature osteoid and osteoblasts with regularly shaped nuclei and abundant cytoplasm.
- The lesion merges with the surrounding trabecular bone.
- Giant cells may be present.

Management

- Unlike osteoid osteoma, osteoblastoma is not a self-limiting process.
- It is a benign, locally aggressive lesion.
- Treatment consists of curettage or marginal excision and usually treatment with an adjuvant agent such as phenol.
- Local recurrence rates are 10–20%.

Malignant Bone Tumors

Osteosarcomas

Etiology

- Malignant spindle cell neoplasms that produce osteoid and bone are classified as osteosarcoma.
  - The majority (85%) of osteosarcomas arise de novo and are known as primary osteosarcomas.
  - Primary osteosarcomas may be differentiated based on clinical, radiographic, and histologic features into intramedullary and surface subtypes.
    - Intramedullary subtypes include
      1. High-grade intramedullary (classic or conventional)
      2. Low-grade intramedullary
      3. Telangiectatic
    - Surface subtypes include
      1. Parosteal
      2. Periosteal
      3. High-grade surface
  - In addition, secondary osteosarcomas may occur within prior pathologic lesions and typically occur in older patients.
- The most common forms of secondary osteosarcoma include
  - osteosarcoma of Paget disease
  - post-radiation osteosarcoma.

Genetics

- Most cases of osteosarcoma are sporadic; however, approximately 70% of osteosarcomas demonstrate a chromosomal abnormality.
- Genetic predisposition is seen in patients with mutations in tumor-suppressor genes such as Li–Fraumeni Syndrome (p53 gene) and retinoblastoma (RB1 gene).

Epidemiology

- High-grade intramedullary or classic osteosarcoma accounts for 80% of all reported cases of osteosarcoma and occurs in children and adolescents at areas of rapid skeletal growth with peak incidence during the second decade of life.
- The most common location is the metaphysis of long bones, especially at the distal femur or proximal tibia.
- High-grade intramedullary osteosarcoma may also occur in the
  - proximal femur
  - proximal humerus
  - pelvis
  - axial skeleton

Clinical History

- Patients present with nonspecific, deep-seated pain that may interrupt sleep.
- A mass, decreased joint motion, or local warmth or erythema may be present.
- Approximately 5–10% of patients will present with a pathologic fracture.
- Metastases are clinically detectable in 10–20% of patients at initial presentation.
- Osteosarcomas metastasize via a hematogenous route and most commonly will travel to lung (80–85%) or bone.
- The most common stage at presentation is IIB (high-grade, extracompartmental).

Differential Diagnosis

- Ewing sarcoma
- Metastatic carcinoma
- Osteomyelitis
- Aneurysmal bone cyst (telangiectatic subtype)
- Fibrous dysplasia (low-grade subtype)

Imaging

- XR:
  - High-grade intramedullary:
    - Aggressive lesion with cortical destruction
    - Ill-defined borders
    - Osteoblastic, osteolytic, or mixed features and an associated soft tissue mass
- Telangiectatic:
  - Eccentric, osteolytic lesion expanding or disrupting the metaphysis
  - May resemble an aneurysmal bone cyst
  - Higher rate of pathologic fracture (25%)
- Low-grade:
  - Less aggressive appearance with lytic, blastic, or mixed features
  - Ossified septa and sclerosis may be present
  - May resemble fibrous dysplasia
- Parosteal:
  - Densely ossified, lobulated mass, arising most commonly from the distal femur/proximal tibia with sparing of the medullary canal
- Periosteal:
  - Radiolucent mass that usually spares medullary canal
  - Commonly associated with "sunburst" pattern or "Codman triangle"
- High-grade surface:
  - Aggressive lesion with partial mineralization and tumor extension into surrounding soft tissues with disruption of the underlying

cortex

- MRI:
  - Critical part of the evaluation of osteosarcoma
  - Clearly demonstrates
    - extent of tumor invasion into surrounding soft tissue
    - neurovascular involvement
    - extent of marrow replacement
    - presence of discontinuous or skip metastases
- Bone scan:
  - Important in initial evaluation
  - Will show sites of increased metabolic activity concerning for metastases
- CT:
  - CT of the chest is performed for staging purposes, to evaluate for presence of pulmonary metastases.

Lab Tests

- Not diagnostic but useful once the diagnosis is established.
- Alkaline phosphatase (ALP) and lactate dehydrogenase (LDH) levels assess for increased osteoblastic or osteoclastic activity and elevated levels are associated with a worse prognosis.

Histology

- High-grade intramedullary:
  - Malignant mesenchymal cells with pleomorphic nuclei and occasional mitotic figures.
  - There must be bone or osteoid production without osteoblastic rimming.
  - Further classified based on dominant extracellular matrix (osteoblastic, chondroblastic, or fibroblastic).
- Telangiectatic:
  - Multiple hemorrhagic cavities, small amounts of osteoid and high-

grade osteosarcoma cells within the septa.

  - Giant cells may be present.
- Low-grade:
  - Well-differentiated cells within woven trabecular bone and fibrous stroma with *small amounts* of osteoid, atypia, and mitotic figures.
- Parosteal:
  - Low-grade, well-differentiated fibrous stroma with osseous components.
  - Parallel trabeculae or "pulled steel wool" pattern. May have a cartilaginous cap.
- Periosteal:
  - Intermediate grade with a mostly cartilaginous matrix and small amounts of osteoid.
- High-grade surface:
  - Similar to conventional or high-grade intramedullary osteosarcoma.

Management

- Management begins with a tissue diagnosis via biopsy.
- Biopsy should be performed under the supervision of the treating surgeon and should follow basic oncologic principles keeping in mind that the biopsy tract will need to be excised if the mass is determined to be a sarcoma.
- Once the diagnosis is established, treatment consists of
  - preoperative (neoadjuvant) chemotherapy for 8–12 wks
  - wide surgical excision, and postoperative (adjuvant) chemotherapy for 6–12 mo.
- Wide resection may consist of
  - amputation or limb salvage with reconstruction via prosthesis
  - allograft or some combination, depending on location, neurovascular involvement, and prior contamination of the tumor site.
  - parosteal osteosarcomas and low-grade intramedullary

osteosarcomas may be managed with wide resection only.

Prognosis

- 10-yr survival rates for patients with localized osteosarcoma are 60–78%.
- Survival rates fall to 20–30% for patients with clinically evident metastases at presentation.
- Poor prognostic factors include
  - primary tumor in the axial skeleton
  - elevated LDH or ALP levels
  - poor response to neoadjuvant chemotherapy (< 90% tumor necrosis)
  - skip metastases

Malignant Fibrous Histiocytoma of Bone

Epidemiology

- Malignant fibrous histiocytoma (MFH) is a rare tumor that accounts for only 5% of malignant tumors of bone.
- MFH may be associated with
  - a pre-existing bone abnormality such as a bone infarct
  - Paget disease or fibrous dysplasia in up to 20% of cases
  - can be seen in irradiated bone.
- This tumor may affect patients of any age; however, more commonly affects adults between the third and sixth decades of life.

Clinical History

- Patients present with increasing pain with or without swelling of the affected extremity.
- Pathologic fracture is common at the time of presentation.
- MFH is most commonly found in the metaphysis of long bones, especially the distal femur or proximal tibia.

Differential Diagnosis

- Osteosarcoma
- Giant cell tumor of bone
- Osteomyelitis
- Metastatic adenocarcinoma

Imaging

- XR:
  - Eccentric lesion with an osteolytic or permeative appearance and a wide zone of transition.
  - Little or no periosteal reaction is seen which can help differentiate this tumor from osteosarcoma.
  - An associated soft tissue mass is commonly seen.

Histology

- Features of MFH include
  - bundles of fibers
  - spindle-shaped, fibroblast-like cells arranged in a cartwheel or storiform pattern
  - giant cells and infiltration of inflammatory cells, predominantly lymphocytes.

Management

- Management begins with a tissue diagnosis via biopsy, using the principles discussed before.
- Once the diagnosis is established, treatment consists of
  - preoperative (neoadjuvant) chemotherapy
  - wide surgical excision
  - postoperative (adjuvant) chemotherapy for 6–12 mo—similar to osteosarcoma
- Wide resection may consist of limb salvage with reconstruction or amputation.

Prognosis

- 10-yr survival rates for patients with MFH are approximately 40–45%.
- Patients with inadequate surgical margins, axial skeleton lesions, and older age at presentation have a notably worse outcome.

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CARTILAGE TUMORS

T. SEAN LYNCH

Benign Cartilage Tumors

Enchondromas

Epidemiology

- The second most common benign cartilage tumor. Incidence is unknown as majority of lesions are found incidentally.
- These lesions can occur at all ages, but most common between adolescents and adults (ages 10–60).

Etiology

- Related to incomplete enchondral ossification with chondroblasts migrating from the physis to the metaphysis and proliferating during skeletal growth.

Clinical History

- These lesions are asymptomatic and often found incidentally.
- Over half of these tumors occur in small tubular bones with the majority occurring in the hand (60%).
- Other locations include metaphysis or diaphysis of long bones such as proximal humerus, distal femur, and tibia.
- These lesions can be painful after pathologic fracture, particularly within the hand and feet.
- Enchondromas can disrupt the epiphysis and thus lead to shortening and angular deformities.

Differential Diagnosis

- Bone infarct
- Low-grade chondrosarcoma

Imaging

- XR:
  - Well-defined, radiolucent intramedullary lesion.
  - Classic appearance involves rings and stippled ("popcorn") calcifications within the lesion.
  - Radiographic appearance is more important than histology for differentiating enchondroma from low-grade chondrosarcoma.
- MRI:
  - Not necessary for diagnosis, but T2 lesion is bright and lobular with no bone marrow edema or periosteal reaction present.
  - There can occasionally be a streak of cartilage from the lesion that is referred to as "sled runner tracks."

Histology

- Hypocellular with bland hyaline cartilage and small chondroid cells in the lacunar space.
- Low power analysis shows mature hyaline cartilage lobules separated from normal marrow.
- Lesions from the hand are more hypercellular with abundant extracellular matrix, but no myxoid component.

Management

- Generally, this lesion is treated with observation with serial x-rays initially to observe for interval growth.
- Initial pathologic fractures of the hand should be allowed to heal with immobilization.
- Curettage and bone grafting should be reserved for any lesion that exhibits changes on serial radiographs.

Related Conditions

- Ollier disease:

  - Multiple unilateral enchondromas in long bone diaphysis.
  - Deformity of the bone is a frequent feature that can cause limb-length discrepancy, short stature, and limb bowing.
  - Treatment is focused on correcting these deformities.
  - There is a 10–30% chance of malignant transformation into chondrosarcoma.
- Maffucci syndrome:
  - Multiple enchondromas with soft tissue angiomas.
  - 100% chance of malignant transformation into chondrosarcoma.
  - Increased risk of visceral malignancies such as GI malignancies and astrocytomas.

Osteochondroma

Epidemiology

- The most common benign bone tumor.
- Incidence is unknown as majority of lesions are asymptomatic.
- Most lesions are identified in first 2 decades of life.

Etiology

- This lesion is thought to arise from the growth-plate that herniates through the bony cortex and then begins to grow by enchondral ossification just underneath the periosteum.

Clinical History

- These lesions are asymptomatic and grow in size until patient reaches skeletal maturity.
- When they are close to skin surface, they can be described as firm and immobile masses.
  - They can cause discomfort depending on the size and location as they can compress nerves, irritate bursa, or the stalk can fracture.
  - They are most commonly present about the knee on the bone surface or at the sites of tendon insertion with lesions occurring most commonly in the distal femur and proximal tibia as well as the proximal humerus and pelvis.

- In addition, subungual exostosis can occur beneath the nail of the distal phalanx in adolescents and young adults.

Differential Diagnosis

- Parosteal osteosarcoma
- Myositis ossificans

Imaging

- XR:
  - Sessile or pedunculated mass on bone surface with lesion near the growth plate.
  - Medullar cavity of the bone is continuous with the stalk of the lesion and the cortex of the underlying bone is continuous with the cortex of the stalk.
  - Cartilage cap is radiolucent that decreases in size with time.
- MRI:
  - Important to obtain in patients with progressive symptoms from an osteochondroma to evaluate the size of the cartilage cap and if there is any concern for malignant transformation—secondary chondrosarcoma.
  - No set value but it should be suspected if the cap is thicker then 1 cm in an adult or a documented increase of greater than 2 cm.

Histology

- Chondrocytes present within lesion have a uniform appearance without pleomorphism or multiple nuclei.
- Stalk contains cortical and trabecular bone.
- Cartilage cap consists of hyaline cartilage that is organized like a growth plate.

Management

- Nonoperative treatment: asymptomatic lesions or patients who are still growing.
- Relative indications for surgical excision include
  1. Symptoms from soft tissue irritation

2. Symptoms from frequent traumatic injury
3. Symptoms from nerve or vascular irritation
4. Significant cosmetic deformity
5. Concern for malignant transformation

- Excision occurs at the base of the stalk as removal of the perichondrium over the cartilage cap allows for decreased chance of recurrence.

Related Conditions

- Multiple hereditary exostosis:
  - Skeletal dysplasia disorder characterized by multiple osteochondromas with an autosomal dominance inheritance pattern caused by mutations in EXT 1, EXT 2, and EXT3 genes.
  - Patients have deformed joints and short statures with similar skeletal deformities, radiographically and histologically, as solitary osteochondromas.
    - Deformities include
      - forearm bowing and shortening
      - ulnar deviation of the hand
      - radial head subluxations/dislocations.
    - Surgical excision should be reserved for these situations as excision can improve motion in these patients.
    - Risk of malignant transformation is 5–10%.

Chondroblastoma

Epidemiology

- A predominately epiphyseal lesion in young patients with 80% of patients less than 25 years of age. M:F—2:1.

Etiology

- Believed to arise from the cartilaginous epiphyseal plate.
- Categorized as cartilage tumors due to the presence of chondroid matrix; however, type II collagen does not get expressed by these

tumor cells.

- Possible genetic component as patient may have genetic abnormalities present at chromosome 5 and 8.

Clinical History

- These lesions are usually found about the knee with most chondroblastomas being found in the distal femur or proximal tibia.
- Other lesion sites include proximal humerus and femur as well as the calcaneus.
- Patients often present with progressive pain and tenderness at the tumor site as well as decreased range of motion with muscle atrophy about the affected joint.
- In addition, due to this lesion’s proximity to the knee and shoulder joints, synovitis is common.

Differential Diagnosis

- Giant cell tumor
- Osteomyelitis
- Clear cell chondrosarcoma

Imaging

- XR:
  - Well-circumscribed, centrally located epiphyseal lytic lesion with thin sclerotic rim.
  - Lesion will often cross physis into metaphysis with possible cortical expansion of the bone present.
  - Soft tissue extension is rare.
- MRI:
  - Useful for diagnosing this tumor as T2-weighted images are hypointense with significant edema.

Histology

- This lesion is highly cellular with round or polyhedral cells with very large nuclei.

- Calcifications are arranged in a "chickenwire" or cobblestone pattern with occasional multinucleated giant cells present, and this helps to confirm diagnosis.

Management

- Extended intralesional curettage and bone grafting with adjuvant treatment (liquid nitrogen, phenol, or argon beam coagulation) in order to decrease local recurrence.
- Overall, local recurrence rate is 10–15%.
- Of note, rare occurrence of metastasis to the lungs (2% of patients).
  - This is an indication for surgical resection.
  - Chemotherapy has not been shown to be effective for benign chondroblastomas.

Chondromyxoid Fibromas

Epidemiology

- The rarest benign cartilage tumor that is present in second and third decades (M > F).

Etiology

- Believed to arise from remnants of the growth plate.
- Possible genetic involvement with rearrangement of chromosome 6 at position q13.

Clinical History

- Patients present with pain and swelling about site of lesion.
- Most common locations are the long bones of the lower extremity, particularly present in the metaphysis of the tibia.
- Occasionally can be located in the bones of the foot and hand.

Differential Diagnosis

- ABC
- Chondrosarcoma
- Non-ossifying fibroma (NOF)

- Enchondroma
- Chondroblastoma

Imaging

- XR:
  - Well-defined, sharply demarcated lytic lesion that is eccentrically present within the metaphysis.
  - At times, it can have a soap-bubble appearance.
  - This tumor can also thin the cortex and cause expansion of the bone.
  - Rarely, calcifications are present within lesions.

Histology

- Low power reveals lobules of fibromyxoid tissue with peripheral hypercellularity; meanwhile, high power reveals myxoid stroma with stellate cells.
- Multinucleated giant cells are a feature of CMF.

Management

- Treatment consists of intralesional curettage and bone grafting.
- Metastasis has not been reported in cases of CMF; however, local recurrence is about 20–30%.
- En bloc resection with reconstruction is saved for CMF tumors that recur or are locally aggressive.

Malignant Cartilage Tumors

Chondrosarcomas

Epidemiology

- Present in older patients (40–75 years of age) with slight male predominance.

Etiology

- These can occur either in a primary form or a secondary form from a benign cartilage lesion.

- Primary chondrosarcoma includes:
  1. Low-grade—Grade 1 or 2 (85% of chondrosarcomas).
  2. High-grade—Grade 3.
  3. De-differentiated chondrosarcoma—high-grade lesions that develop from low-grade chondroid lesion.
  4. Mesenchymal chondrosarcoma—rare biphasic variant presenting in younger patients that can occur at several discontinuous sites as well as in the soft tissue.
  5. Clear cell chondrosarcoma—malignant immature cartilage tumor that presents with gradual pain during third or fourth decade. Presents as an epiphyseal lesion that can be mistaken for chondroblastoma—usually seen in the proximal femur.
- Secondary chondrosarcoma includes:
  1. Osteochondroma ($<1\%$ risk of malignant transformation).
  2. Enchondromas ($<1\%$ risk of malignant transformation).
  3. Multiple hereditary exostosis (1–10% risk of malignant transformation).
  4. Ollier disease (25–40% risk of malignant transformation).
  5. Maffucci syndrome (100% risk of malignant transformation).

Clinical History

- Persistent dull pain over a long time period is the most common symptom.
- Patients can also present with a slowly growing mass or bowel/bladder issues secondary to a pelvic mass.
- Most common locations for lesions include pelvis, proximal femur, shoulder girdle.
- Aggressiveness is determined by tumor grade.

Imaging

- XR:
  - Low-grade lesions appear similar to enchondromas with additional

cortical thickening/expansion with endosteal erosion.

  - High-grade lesions less well-defined with cortical destruction and a soft tissue mass.
  - De-differentiated chondrosarcoma shows signs of both low- and high-grade lesions with calcified intramedullary lesion and an adjacent destructive lytic lesion.

- Bone scan:
  - All grades of chondrosarcoma typically are bright.
  - CT/MRI:
    - not necessary for diagnosis, but helpful to determine cortical destruction, marrow involvement, any soft tissue masses, and for preoperative planning.

Histology

- Low-grade lesions show few mitotic figures with bland histologic appearance.
- High-grade lesions exhibit hypercellular chondroid stroma with sites of cartilage that infiltrate the bony trabeculae.
- Atypical features are also sometimes seen with binucleate chondrocytes within the lacunae, which is diagnostic.
- De-differentiated chondrosarcomas are biphasic with low-grade chondroid component and high-grade spindle cell component.

Management

- Grade 1:
  - intralesional curettage; however, if lesion is present in pelvis this necessitates wide excision.
  - Local recurrence is 10% with recurrent lesions having a 10% chance of increasing in Grade.
- Grade 2, 3:
  - wide surgical resection, no chemotherapy, no radiation.
- De-differentiated chondrosarcomas:
  - wide surgical resection.

- Chemotherapy for de-differentiated is controversial.
- Rate of recurrence has been found to correlate with increased telomerase activity in chondrosarcoma.

Prognosis

- Survival based on the grade of the lesion
  - Grade 1: 90%
  - Grade 2: 60–70%
  - Grade 3: 30–50%
  - De-differentiated: 10%

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FIBROUS TUMORS

RONAK M. PATEL

Metaphyseal Fibrous Defects

1. Nonossifying Fibromas (NOF)
2. Fibrous Cortical Defects (FCD)

Epidemiology

- Most common benign lesions of the skeletal system.
- Incidence of 30–40% in skeletally immature patients and frequently found incidentally.
- These lesions occur more frequently in males compared to females (2:1) and peak during the second decade of life.

Etiology

- Etiology remains unknown.
- No osseous metaplasia.
- NOFs do NOT make bone rather are replaced with bone over time.

Clinical History

- Asymptomatic and often found incidentally.
- Occasional symptoms of pain, swelling, or tenderness on exam can be seen secondary to a stress fracture or a displaced fracture.
- No associated soft tissue mass is found.

Differential Diagnosis

- FCDs:

- osteoid osteomas
  - intracortical abscesses
  - stress fractures
  - intracortical osteosarcoma
- NOFs:
  - aneurysmal bone cysts
  - chondromyxoid fibroma
  - fibrous dysplasia (FD)
  - desmoplastic fibroma

Imaging

- Bone scans, CT, and MRI are rarely needed.
- Radiographs with history and physical exam remain mainstay of diagnosis.
- Radiographic findings:
  - FCDs:
    - Small (1–3 cm) round-ovoid lytic lesions eccentrically located in the metaphysis or metaphyseal–diaphyseal junction.
    - Intra or juxtacortical with a peripheral rim of sclerosis.
    - Subperiosteal.
    - No communication to intramedullary bone.
  - NOFs:
    - (1–7 cm) Eccentric, lytic, cortically based lesions that involve the medullary canal with varying degrees.
    - Peripheral sclerotic rim with frequent scalloping—may thin, but not breach, overlying cortex.
    - Can have an internal "bubbly" appearance resulting from thin septae.
    - Occur in the metaphysis and appear to migrate to the diaphysis as bone grows.
- CT can detect change in size or determine cortical integrity.

- MRI findings are hypotense on T1 with variability on T2; useful in distinguishing from cystic lesions if clinical picture not classic.

Pathology

- Gross:
  - Both lesions display somewhat friable red-brown tissue with foci of yellow discoloration
- Microscopic:
  - Highly cellular tissue of unremarkable (atypical cells uncharacteristic) fibrohistiocytic spindle cells arranged in storiform pattern interspersed with multi-nucleated giant cells.
  - Hemosiderin deposits and scattered lymphocytes are typical.

Management

- Nonoperative management with full weight-bearing, observation, and serial x-rays initially to observe for interval growth.
  - Most spontaneously regress at skeletal maturity (NOFs take longer because they are larger than FCDs).
  - Pathologic fractures can be treated with cast immobilization until the fracture has healed; subsequently, biopsy, curettage, and bone grafting should be performed in effort to reduce risk of re-fracture.
- Large symptomatic NOFs and atypical lesions should also undergo biopsy followed by curettage and grafting.
- Graft: autologous bone graft vs. substitute (Allograft bone chips, demineralized bone matrix, and ceramics); all efficacious.

Associations

- Multifocal NOF present in up to 10% cases, most frequently in patients with neurofibromatosis (von Recklinghausen disease) or Jaffe–Campanacci syndrome (café-au-lait spots, mental retardation, hypogonadism, cryptorchidism, as well as ocular and cardiovascular anomalies).

Fibrous Dysplasia

Epidemiology

- Relatively common, slow-growing lesion composed mainly of bone and fibrous tissue but occasionally foci of cartilage.
- Occur at any age, but ~75% in patients <30 yrs and ~75% are monostatic (vs. polyostotic).

Etiology

- Long considered a developmental abnormality, but relatively recent findings of activating mutations in the alpha subunit of stimulatory G protein (GNAS1) suggest it is actually a benign neoplasm.
- Inability to produce mature lamellar bone leaves areas with poorly mineralized trabeculae.

Clinical History

- Asymptomatic and often found incidentally.
- The femur, tibia, skull (& face), or ribs most commonly affected. Symptomatic from pathologic fracture.
- Deformity may occur as result of repeated minor fractures on a long bone (Classic Shepherd's crook deformity of proximal femur).

Differential Diagnosis

- Low-grade intramedullary osteosarcoma

Imaging

- XR:
  - Well-defined, central lytic lesion with less prominent sclerotic rim located in diaphyseal/metaphyseal region.
  - Overall "ground glass" appearance with expansion causing cortical thinning.
- Bone scan: increased uptake

Pathology

- Gross:

- Firm, whitish tissue of gritty consistency
- Microscopic:
  - Poorly mineralized immature fibrous tissue surrounding islands of irregular trabeculae of woven bone.
  - "Chinese letters" or "alphabet soup" appearance.
  - Secondary reactive changes: cartilage, giant cells, hemosiderin, foamy histiocytes, fracture callus.
  - No osteoblastic rimming of osteoid.

Management

- Nonoperative management with full weight-bearing, observation, and serial x-rays for asymptomatic lesions.
  - Medical treatment with bisphosphonates can provide pain relief.
- Operative indications include
  1. painful lesions
  2. impending/acute pathologic fracture
  3. severe deformity
  4. neurologic compromise
     - Curettage and bone-graft the lesion with cortical allograft (cancellous autograft is replaced by dysplastic bone!)
     - Internal fixation to achieve pain control (IM nail > plate)
     - Osteotomies for deformities to restore mechanical axis and reduce impingement

Associations

- Mazabraud syndrome
  - associated soft tissue intramuscular myxoma
- Albright-McCune syndrome
  - polyostotic involvement with café-au-lait spots
  - coast of Maine patch
  - short stature

    - endocrinopathies (precocious puberty)
    - Germline mutation in GNAS1 gene
- Rare sarcomatous transformation
    - usually secondary to irradiation

Osteofibrous Dysplasia

Epidemiology

- Most often seen in young children and behaves less aggressively as the child gets older.

Etiology

- Initially considered variant of Fibrous Dysplasia; however, OFD is a distinct entity.
- Genetic relationship between OFD and adamantinoma.

Clinical History

- Painless, but rapidly growing cortical tumors, almost exclusively found in the tibia and/or fibula.
- Deformity may occur as result of repeated minor fractures or tumors.

Differential Diagnosis

- Fibrous Dysplasia
- Adamantinoma

Imaging

- XR:
    - Eccentric intracortical osteolysis with thinning of the overlying cortex.
    - Lesions are usually extensive, involving the anterior cortex of the diaphysis or metaphysis—can lead to tibial bowing.

Pathology

- Microscopic:
  - Irregular spicules of trabecular bone lined with osteoblasts that may produce a rim of lamellar bone in a bed of collagenous stroma.
  - Typically, keratin negative (unlike Adamantinoma).

Management

- Nonoperative management with full weight-bearing, sometimes bracing can help with deformity.
  - Follow-up with observation and serial x-rays for asymptomatic lesions.
- Operative intervention may be needed for correction of deformity, which consists of curettage and bone grafting.

Associations

- Trisomies 7, 8, 12, 21.

Adamantinoma

Epidemiology

- Most often seen in adults between 20 and 30 yrs of age. M > W.

Etiology

- Epithelioid cells strongly positive for keratin.
- Osteofibrous dysplasia (OFD) is thought to be a precursor to this lesion.
- Relatively low-grade malignancy that is locally invasive, but with late metastases in 20% of cases.

Clinical History

- Rare, slow-growing neoplasm of long bone with >90% located in tibial diaphysis.
- Patients present with insidious onset of pain and swelling.

Differential Diagnosis

- OFD
- Fibrous dysplasia
- Metastatic carcinoma

Imaging

- XR: Well circumscribed multicystic osteolytic lesion with surrounding rim of sclerosis overlying cortical thinning on the anterior cortex of the tibial diaphysis.

Pathology

- Microscopic: Nests of epithelioid cells intertwined with spindle-shaped collagen-producing cells.
- Gross: Well-circumscribed and rubbery in texture

Management

- Adequate biopsy to prevent confusion with other lesions.
- Requires wide excision to prevent recurrence; if there are significant satellite lesions adjacent to main lesion, radial resection may be required.

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SOFT TISSUE MASSES

JAMES CAMERON

Introduction

- Benign soft tissue masses far outweigh the occurrence of malignant soft tissue masses.
- The majority of soft tissue sarcomas (STS) are seen in patients over age 40.
- STS rarely present with symptoms other than a lump or bump, which makes diagnosis difficult.

Clinical Evaluation

- Age of patient
- Duration
- Fluctuation in size
- Neurogenic symptoms
- Any previous history of cancer
- Family history of cancer/masses

Physical Exam

- Deep masses greater than 5 cm in diameter should be considered malignant until proven otherwise.
- Strongly consider evaluation by an orthopaedic oncologist after appropriate imaging has been performed.

Differential Diagnosis of a Benign Extremity Mass

- Lipoma
- Synovial cyst
- Hemangioma
- Abscess
- Intramuscular myxoma
- Fibromatosis (desmoid)
- Neurofibroma
- Neurilemmoma
- Hematoma

- Lipoma:
  - Common benign fatty tumor
  - High signal on T1 and T2
  - Deep lipoma has a 5% lifetime conversion to liposarcoma
  - Observe vs. excise
- Synovial cyst:
  - Fluctuate in size
  - Para-articular masses, trans-illuminate light
  - Excise if symptomatic or cosmetically unacceptable.
- Hemangioma:
  - Common superficial mass in children
  - Aching pain that tends to worsen with exercise
  - Fluctuates in size
  - Pain is often influenced by hormonal changes (young women and their menstrual cycles or on oral contraceptives)
  - Observe and treat with activity modification and NSAIDs vs. excise (high recurrence rates)

- Abscess:
  - Red
  - Swollen
  - Warm
  - Tender
  - Treat with surgical decompression/drainage and antibiotic therapy
- Intramuscular myxoma:
  - Two-thirds affect women
  - Occurs primarily in patients aged 40–70
  - Well-defined homogenous tumor
  - Low signal on T1, high signal on T2 but does not enhance with contrast
  - Typical treatment is with surgical excision
- Fibromatosis (desmoid tumor):
  - Common benign tumor
  - Associated with Gardner syndrome
  - Grossly looks like scar tissue
  - Low signal on T1 and T2
  - Approximately 50% recurrence after removal due to its infiltrative nature and difficulty obtaining negative margins
  - Treat with wide excision; +/− radiation; +/− chemotherapy
- Neurofibroma:
  - Associated with von Recklinghausen disease (neurofibromatosis type I)
  - Has no capsule, therefore difficult to resect; may involve a peripheral nerve, which then precludes excision (plexiform neurofibroma); solitary lesion that is excised has good prognosis.
  - Lesions in patients with von Recklinghausen disease may become malignant and develop into a malignant peripheral nerve sheath tumor (MPNST); they have poor 5-yr survival.

- Neurilemmoma:
  - Benign, encapsulated nerve sheath tumor
  - Positive Tinel sign; high signal on T2 known as a “target sign” with a lesion involving a peripheral nerve
  - Treat with excision if symptomatic.
- Soft tissue masses associated with cancer:
  - Lung and renal cell cancer may cause soft tissue metastasis.
  - Lymphoma and multiple myeloma may have a soft tissue component.

Soft Tissue Sarcomas

Introduction

- Rare malignancy that arises from mesodermal tissue.
- Twice as common in the lower extremity vs. the upper extremity.
- There are >50 different types of sarcoma, but the most common include liposarcoma, leiomyosarcoma, synovial sarcoma, fibrosarcoma, and high-grade pleiomorphic undifferentiated sarcoma (HGPUS).
- Hematogenous metastasis to the lung is most common; certain subtypes have an increased propensity to spread via the lymphatic system (e.g., angiosarcoma, synovial sarcoma).

Risk Factors

- Certain chemicals (e.g., herbicides)
- Exposure to external beam radiation
- Lymphedema

Diagnosis

- Physical exam: STS are usually nontender, well circumscribed, and firm (superficial sarcomas are typically discovered when smaller in size, for obvious reasons).
- Examine for local and regional lymphadenopathy.

Imaging

- Orthogonal x-rays
- MRI with gadolinium
- Chest radiograph and chest CT scan for staging purposes

Biopsy Options

- Fine-needle aspiration, core needle biopsy, and open biopsy—discussed in introduction to tumors
- Multiple immunohistochemical markers are now used for diagnostic purposes.
  - Examples include
    - S100 for benign nerve sheath tumors
    - MDM2 for liposarcoma
    - smooth muscle actin (SMA) for leiomyosarcoma.

Classification

- There are multiple staging systems but the two systems most commonly used are the staging system of the Musculoskeletal Tumor Society and the American Joint Committee on Cancer (AJCC).
- The grade and presence of metastasis are used in both staging systems.
- Neither system has ever been subjected to statistical validation tests. Rhabdomyosarcoma has its own staging system.

Common Translocations Seen in Soft Tissue Sarcomas

- Alveolar rhabdomyosarcoma: t(2;13)
- Ewing sarcoma: t(11;22)
- Myxoid liposarcoma: t(12,16)
- Synovial sarcoma: t(X;18)

Treatment

- Small superficial low or high-grade STS may be managed with surgery alone.
- Radiation therapy:
  - Studies have shown it improves local control.
  - Radiation should be used when there are positive margins histologically.
  - There is debate about its use in other circumstances, as well as whether it should be employed preoperatively or postoperatively.
- Chemotherapy:
  - Common drugs used are doxorubicin (an anthracycline) and ifosfamide (alkylating agent)
  - Meta-analysis by Pervaiz et al., showed marginal efficacy for localized, resectable STS.
  - However, in patients with advanced disease most clinicians support its use.

Important Notes

- Liposarcoma: most common soft tissue malignancy in adults.
- Alveolar rhabdomyosarcoma: most common STS in children.
- Epithelioid sarcoma/synovial sarcoma typically occur in the distal extremities (hand and foot respectively).

- Synovial sarcoma:
  - resembles synovial tissue histologically; most common STS to show calcification on imaging.
  - may occur near a joint but not usually within them.
- Fibrosarcoma: herringbone pattern of growth histologically.
- STS that may spread via the lymphatics:
  - Rhabdomyosarcoma
  - Angiosarcoma
  - Clear-cell sarcoma
  - Epithelioid sarcoma
  - Synovial sarcoma.

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CYSTIC TUMORS

T. SEAN LYNCH

Aneurysmal Bone Cyst

Epidemiology

- Aneurysmal Bone Cysts (ABCs) comprise 1–6% of all primary bone tumors with equal distribution among the sexes.
- This lesion usually occurs during the first 2 decades with the median age 11.1 yrs.
- Two-thirds of ABCs are primary lesions while the other one-third form secondarily from another primary tumor such as giant cell tumors (GCTs) (most common), osteoblastomas, angiomas, and chondroblastomas.

Etiology and Pathophysiology

- There is much debate regarding the cause of these lesions.
- Current hypothesis include:
  1. Vascular—osseous AV malformation that causes reactive lesion
  2. Bony hemodynamic changes that increase venous pressure and dilate vascular beds
  3. Traumatic—bony trauma with an abnormal reparative process that causes lesion
  4. Genetic—somatic mutation, which causes translocation of osteoblast cadherin-11 gene (CDH11) on chromosome 16q22 with coding sequence of ubiquitin-specific protease gene (USP6) on chromosome 17p13.
- Progression of ABCs have been divided into 4 stages:

1. Initial phase—osteolysis of marginal part of the bone with discrete elevation of the periosteum
2. Growth phase—progressive destruction of bone
3. Stabilization phase—stereotypical appearance of ABCs present in this phase as an expansile lesion with distinct bony shell and osseous separations
4. Healing phase—progressive ossification of the lesion

Clinical History

- Benign and typically associated with pain, soft-tissue swelling, or the presence of a palpable expansile mass.
- Pain is attributed to microfracture of the bone at the site of the lesion; however, pathologic fracture as a presenting symptom is rare.
  - These cysts primarily develop about the knee; commonly the metaphyseal region of the femur, tibia, humerus, and fibula.
  - Other sites include skull and posterior elements of the spine.

Differential Diagnosis

- Include benign lesions such as unicameral bone cysts, chondromyxoid fibroma, chondroblastoma, GCT, or osteoblastomas.
- ABCs need to be differentiated from telangiectatic osteosarcoma given its similar radiographic and histologic similarities.

Imaging

- XR:
  - Well-defined, radiolucent cystic lesion with bony septae (“bubbly” appearance) within the metaphyseal portion of the bone, typically eccentrically placed.
  - The mass usually remains contained by thin shell of cortex, but does have the capability to elevate periosteum and can occasionally extend into the soft tissue.
- MRI:
  - Classic fluid-filled levels that demonstrate layering of serum and

blood components within cystic areas of the lesion.

  - This finding is very suggestive of ABC, but is not pathognomonic as telangiectatic osteosarcoma, GCT, and secondary ABCs can also demonstrate this layering.

Histology

- Findings consist of two components:
  - cavernous blood-filled space with a nonendothelial cavity lining that consists of benign giant cells
  - spindle cells with thin strands of bone present in fibrous tissue of septae

Management

- If not treated, ABCs can progress with continued bony destruction that can cause pain and potential fracture.
  - The goal of treatment is to completely eradicate the lesions while preserving as much normal host bone as possible.
  - Early intervention is recommended consisting of open biopsy with frozen section and definitive treatment after diagnosis is confirmed.
- The mainstay treatment option includes intralesional curettage and bone grafting.
  - The goal of the curettage is to remove the whole tumor as well as the cyst-wall lining in order to prevent recurrence.
  - When compared to a small fenestration in the bone, it has been found that a large cortical window increases the chances of tumor removal and thus decreases the chances of recurrence.
  - Once the tumor has been removed, bone graft substitute is placed in the void in order to assist in healing.
- Other options include:
  - Cryotherapy
  - Sclerotherapy
  - Radionuclide ablation

- En-bloc resection (generally reserved for lesions in expendable bone locations such as the fibula and clavicle that can be performed without affecting cosmesis or function).

Recurrence

- Local recurrence rate is approximately 20% and is associated with young age (less than 12) and open growth plates.
- Most recurrence occurs within 24 months of surgery; thus, radiographic surveillance is needed for 2 years after surgery.
- Histology can also give some insight to recurrence as biopsies with primarily osteoid component portend a good prognosis as this suggests that the cyst was in the healing phase.
- For local recurrence, repeat curettage and grafting is indicated.

Unicameral Bone Cyst

Epidemiology

- Unicameral bone cysts (UBCs) comprise of about 3% of all biopsied bone tumors. M > F.
- These lesions are usually seen during the first 2 decades of life.

Pathogenesis

- There is little known about the development of UBCs, it is thought to involve a growth defect or disturbance of medullary bone formation near or at the growth plate leading to formation of these cysts.
- Based on electron-microscopic findings, several theories that have been proposed for pathogenesis of UBCs are:
  1. Trauma—dysplastic areas have been observed that are believed to be the result of a traumatic event
  2. Vascular—cystic formations as a response to venous occlusion in the intramedullary space
  3. Intraosseous synovial cysts

Clinical History

- These lesions are benign and symptoms are often brought on by trauma with about 50% of these patients presenting with a pathologic fracture.
- The soft tissue about the cyst can be found to be warm and swollen.
- These cysts primarily develop in the proximal humerus or proximal femur, but can also occur in the ileum as well as calcaneus.
- These lesions are generally present in the metaphyseal region of bone adjacent to or involving the growth plate.
- As patient approaches skeletal maturity, UBCs will decrease in size and may heal after growth is completed.

Differential Diagnosis

- Include benign lesions such as ABCs, fibrous dysplasia, and telangietic osteosarcoma.
- ABCs are more expansive than UBCs as UBCs are usually not wider than the physis.

Imaging

- XR:
  - Well-defined, radiolucent cystic lesion within the metaphyseal portion of the bone located centrally with symmetric thinning of cortices.
  - No soft-tissue involvement.
  - A “fallen leaf” sign is pathognomonic and can be observed in which a fragment of the cyst wall has fractured and fallen into the fluid cavity of the cyst.
  - Bone expansion does not exceed the width of the physis.
- MRI: well-defined zone of bright uniform signal on T2 images

Histology

- Cysts walls are lined with a thin fibrous membrane of giant cells, inflammatory cells, and hemosiderin.
- No endothelial cells within lining.

Diagnosis

- Diagnosis can be confirmed with aspiration; however, radiographs are often diagnostic.
- The natural history of UBC is for the lesion to fill in with bone as patient matures skeletally.
  - This requires close follow-up while in the active phase (cyst adjacent to physis) due to recurrence and risk of fracture.

Management

- Management includes intralesional injection of steroids, calcium sulfate, or demineralized bone matrix mixed with bone marrow aspirate, depending on the proximity to the growth plate.
- After acute fracture, lesion will fill in with native bone in about 15% of lesions.
- If the lesion includes the proximal femur, with or without fracture, curettage and bone grafting with internal fixation is an option.
- This should be avoided in active lesions as this can lead to growth arrest.

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OTHER TUMORS

ANDRE R. SPIGUEL

Diseases Of Synovium

Introduction

• Normal synovial membrane is found lining joints, tendons, and bursae.

• It provides lubrication, nutrition for articular cartilage and mediates the exchange of materials between blood and synovial fluid—an ultrafiltrate composed of hyaluronic acid, lubrican, proteinases, collagenases, and prostaglandins.

Pigmented Villonodular Synovitis

Clinical History

• Villous and/or nodular proliferation of the synovium with fat and hemosiderin deposition.

• Affects males and females equally and seen most commonly in the third or fourth decade.

• Usually monoarticular and located within the joint and is typically benign but locally aggressive.

• The knee is most frequently affected, followed by the hip, ankle, shoulder, and elbow.

• The symptoms wax and wane and include significant joint swelling, pain, instability, locking, stiffness, and limited ROM.

• Classically patients will describe repeated aspirations with bloody effusion.

Differential Diagnosis

- Chronic synovitis
- Osteoarthritis
- Rheumatoid arthritis
- Synovial hemangioma
- Lipoma arborescens
- Synovial chondromatosis
- Hemophilia

Imaging

- XR –
  - Soft tissue swelling and possibly juxtarticular erosions and sclerotic margins—early degenerative changes
- MRI –
  - Most diagnostic.
  - Low signal intensity on T1 and T2 weighted images as a result of hemosiderin deposition.

Histology

- Chronic inflammatory synovium with foam cell (lipid laden histiocytes) and occasional giant cells.
- Large amounts of hemosiderin

Management

- Surgery is the mainstay of treatment with complete synovectomy, which can be accomplished open or arthroscopically.
- High recurrence rates, up to 50%.
- Adjuvant with XRT is also used for residual disease; intra-articular radioisotopes have also been used.

Synovial Chondromatosis

Etiology

- Caused by metaplasia of undifferentiated mesenchymal cells in the synovium into nodules of hyaline cartilage

Clinical History

- Affects men twice as often as women and usually occurs between the third and fifth decades.
- Exceedingly rare and usually occurs in large joints (50% hip or knee) but can occur in the hands and feet.
- Presents with pain, swelling, limited range of motion, crepitus, and sometimes even palpable loose bodies.

Imaging

- XR/MRI:
  - Multiple calcified loose bodies of varying sizes, stippled calcification may be present.
  - Usually lesion has marrow in the middle surrounded by bone.

Histology

- Discrete nodules of disorganized cartilage in the synovium.
- Cartilage can display cellular atypia, hypercellularity with crowding–can be confused for a chondrosarcoma without the clinical picture.

Management

- Treatment of choice is surgical removal of loose bodies and total synovectomy.
- Recurrence is common because it is difficult to do a total synovectomy,

Giant Cell Tumor of Tendon Sheath

Clinical History

- Considered the most common neoplasm of the hand.
- May occur at any age but is usually seen in patients 30–50 years of age.
- Women affected twice as often as men.
- Typically present as nodular tumors along the tendon sheaths.
- On exam, it is a firm, lobulated, nontender, solitary mass.

Differential Diagnosis

- Nodular fasciitis
- Tendinous xanthomas
- Granulomatous lesions
- Fibroma of tendon sheath
- Epithelioid sarcoma (most common soft tissue sarcoma of the hand)

Imaging

- XR: can show degenerative changes at the adjacent joint and in 10% of patients bony erosions may be seen.
- Best evaluated on MRI

Histology

- Histologically similar to pigmented villonodular synovitis (PVNS), although it tends to be more solid and nodular
- Xanthoma (foam) cells present
- Multinucleated giant cells
- Collagen stroma
- Hypocellular collagenous zones
- Sheets of rounded or polyhedral histiocytes.

Management

- Marginal excision with up to 10% recurrence rates

Giant Cell Tumor of Bone

Clinical History

- Locally aggressive lesion that usually presents with pain.
- Most common in skeletally mature women in their 20s to 40s.
- Usually epiphyseal – most commonly seen in
  1. the distal femur
  2. proximal tibia
  3. the distal radius.
- 3–4% of the time they can metastasize to the lungs—which requires

resection.

Imaging

- Usually eccentric and juxta-articular, extending to subchondral bone.
- Can appear destructive and expansile extending into the soft tissues

Histology

- Benign appearing multinucleated giant cells dispersed evenly throughout a sea of homogenous, round-oval mononuclear cells.
  - These mononuclear cells look like the nuclei of the giant cells.
- Clinical behavior cannot be predicted from histology.
- Can have malignant degeneration with cellular atypia and increased mitoses

Management

- Classically curettage and bone graft used with 50% recurrence.
- Current techniques involve
  - curettage
  - mechanical burring with high speed instrument
  - adjuvant treatment (phenol, cryosurgery, or argon beam coagulation)
  - stabilization with methyl methacrylate with 25% recurrence rates.
- Marginal resection performed for multiply recurrent lesions, expendable bones, or extensive bone destruction.
- XRT sometimes used with 10% risk of malignant transformation.

Chordoma

Clinical History

- Indolent and low-grade primary malignant bone tumors, which are thought to arise from notochordal remnants and therefore they occur along the midline from the skull base (clivus) to the sacrum (50% of the time).
- 1–4% of all primary bone tumors and they affect men twice as frequently as women, the median age at diagnosis is 58.5 years of

age.

- Pain is the most common presenting symptom and neurologic deficits are common depending on the level of compression of the spinal cord or nerve roots.
- Due to their slow growth and often nonspecific symptoms, they are typically diagnosed at late stages.

Imaging

- Classically appears as an osteolytic lesion centered in the midline associated with a large soft tissue mass.
- XR: midline lytic lesion, appears destructive and poorly marginated, it is often missed.
- Best visualized on CT and MRI.
  - They display prominent contrast enhancement on both CT and MRI.
- MRI:
  - Low signal intensity on T1 weighted images and hyperintense on T2 images.
  - They commonly invade the intervertebral disk space.

Differential Diagnosis

- Metastatic disease
- Multiple myeloma

Histology

- Most chordomas display S-100 immunoreactivity.
- Physaliphorous (soap bubble) cells are pathognomonic for these tumors—abundant eosinophilic vacuolated cytoplasm with nuclei pushed to the side.
- The nuclei are small, round, and darkly staining, they display a moderate amount of nuclear pleomorphism with few mitotic figures.

Management

- Surgery, wide en bloc resection for cure remains the treatment of choice given their low-grade nature.

- Obtaining wide tumor free margins is key; although, not always possible given their location and the regional anatomy.

- Radiation therapy can be used as adjuvant treatment for chordoma with incomplete resection or positive margins, although these tumors are relatively radioresistant.
- Proton beam therapy also appears to offer some improvement in treatment.
- Chemotherapy is not usually effective

Eosinophilic Granuloma

Clinical History

- One of three classic clinical syndromes that are thought to be variations of the same disease—Langerhan Cell Histiocytosis (formerly known as Histiocytosis X).
- Benign, possibly reactive inflammatory condition that may be focal or systemic and the most common site of involvement is bone (80% of the time).
- The etiology is unknown and any bone can be involved, although there is a predilection for flat bones.
- The bone marrow is replaced by Langerhan cells that originate in the marrow and may play a role in immune response.
- Eosinophilic granuloma (EG) has the best prognosis and is the best differentiated form of the disease with an isolated bone lesion.
- If there are multiple bone lesions, the disease is named Hand—Schuller–Christian disease, and it is also associated with exophthalmos and diabetes insipidus.
- Patients are usually 10–20 years old and present with pain, swelling, and usually a soft tissue mass.

Imaging

- XR:
  - Radiolucent lesion, can be well or poorly marginated and often have an aggressive appearance making it difficult to differentiate from a malignancy.

- May have endosteal scalloping and a long, unbroken periosteal reaction. In the spine there can be uniform vertebral collapse called *vertebra plana.*

- CT and MRI are also usually obtained to further delineate the lesion

Differential Diagnosis

- Ewing sarcoma
- Lymphoma
- Leukemia
- Metastasis
- Osteomyelitis

Histology

- Numerous eosinophils and Langerhan cells – indented bean shaped nuclei, finely stippled chromatin pattern
- Small nucleoli
- Birbeck granules (racquet shaped inclusion bodies in cytoplasm seen on electron microscopy)

Management

- Treatment is not standardized.
- Isolated lesions usually resolve spontaneously over time and can be observed.
- Due to the often aggressive appearance of this lesion, open biopsy is often performed.
- If a malignant process is ruled out, then some proceed with open curettage and bone grafting.
- In patients with multiple bone lesions, chemotherapy is often used and it significantly decreases recurrences.

Ewing Sarcoma

Clinical History

- Although rare, it is the third most frequent primary sarcoma of bone, after osteosarcoma and chondrosarcoma.

- It is the second most common bone tumor in children and adolescents, accounting for 3% of all pediatric malignancies.
- It can also rarely be found in the soft tissues.
- Most commonly diagnosed in the second decade of life, infrequent in African-Americans and Asians.
- Male to female ration is 1.5:1.
- Patients usually present with local pain and swelling, systemic symptoms of fever and anemia may be present with nonspecific laboratory studies (elevated WBC and ESR).

Imaging

- Destructive, poorly marginated bone lesion, typically with a large soft tissue mass.
- Usually ill defined and permeative, moth-eaten appearance, with significant periosteal reaction and a laminated, “onion-skin” appearance.
- Tends to arise from the diaphysis or metadiaphysis and can affect any bone—long bones and flat bones are equally affected.
- MRI is used to evaluate the soft tissue mass and intramedullary extent of disease.

Histology

- Uniform, small, round, undifferentiated blue cells with a high nuclear to cytoplasmic ratio.
- Extensive tumor necrosis is usually seen due to rapid growth exceeding blood supply.
- May need immunohistochemistry and cytogenetics to differentiate among other small, round blue cell tumors.
- CD99 is almost universally expressed (95% of cells).
- At the genetic level it is defined by the 11;22 gene translocation, EWS–ETS fusion gene rearrangements (EWS-FL1 translocation detected in 80–95% of cases).

Management

- Treatment involves multiagent chemotherapy, +/− surgery and/or

+/− radiation.

- Ewing sarcoma is extremely radiosensitive and indications for radiation are skeletal maturity and nonexpendable bones (spine and pelvis if the acetabulum is involved).
- Indications for surgery are
  - expendable bones
  - resection/reconstruction with only modest loss of function
  - amputation for distal tumors in patients with significant growth remaining.
- Side effects to radiation treatment:
  - growth arrest
  - pathologic fracture (femur up to 50%)
  - soft tissue fibrosis and contracture
  - local recurrence (20%)
  - 2–3% risk of radiation induced osteosarcoma with dismal prognosis.

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PEDIATRIC ORTHOPEDIC TRAUMA—INITIAL ASSESSMENT

KEITH DOUGLAS BALDWIN • CORINNA C. FRANKLIN

Etiology and Epidemiology

- Trauma is the most common cause of death in children older than 1 year of age.
- Neurologic injury is the most common cause of morbidity and mortality.
- Specifically, the two most common causes of polytrauma in children are motor vehicle accidents and falls.

Differences Between Adult Trauma and Pediatric Trauma

- Thick, active periosteum
  - Allows for assistance, and maintenance of reduction, and makes closed treatment more successful in a child compared to an adult.
- Open physes
  - Limits the utility of orthopedic hardware, but allows for bony remodeling, particularly in younger children and when the injury is closer to the growth plate.
- Possibility of child abuse
  - Must be considered by the orthopaedic physician, particularly for certain patterns.
- Large head

    - Creates unacceptable flexion of the c-spine if an adult spine board is used. Therefore, use a pediatric spine board with a recessed head.
- Large body surface area to mass ratio
    - Increases the chances of hypothermia due to blood loss.
- Smaller blood volume
    - Children can maintain hemodynamic stability longer, but may decompensate suddenly because of their inability to alter their stroke volume as much as adults.

Clinical History

- Clinical history may be difficult to obtain in an injured child.
- The caregivers may be used as an additional source of information.
- The clinician must be alert to note inconsistencies in accounts of injuries in vulnerable populations.
- A femur fracture in a child who is not yet walking is highly suspicious for child abuse.
- The energy of the injury should be documented, as well as the mechanism of injury, as this may give clues to help manage and reduce fractures.

Differential Diagnosis

- The main differential diagnosis in the setting of pediatric orthopedic trauma is accidental vs. nonaccidental trauma.
- Other diagnoses are possible, such as metabolic (rickets) or genetic (osteogenesis imperfect) bone diseases, but are far less common than both accidental and nonaccidental injuries.
    - Although nonaccidental trauma is a clinical diagnosis, it can be one of severe consequences, both if missed or misdiagnosed.
    - As such, some hospitals have designated specialized teams to help deal with this difficult situation.
    - Orthopedic surgeons should be alert for suspicious history

(changing stories, a “fall” in a child who is not yet walking, or an unwitnessed injury/delayed presentation), multiple injuries or old injuries.

  - Classic injuries for child abuse are metaphyseal corner fractures, and posterior rib fractures, though transverse femur fractures are more common.

Physical Exam

- **Primary survey**
  - Airway, Breathing, Circulation, Disability, and Exposure are assessed in the primary survey with a basic exam.
- **Secondary survey**
  - A complete head to toe exam is performed with the patient fully unclothed.
  - A log roll is performed to examine the spine.
    - This takes a minimum of five people:
      - one examiner
      - one for the head
      - three for the body
    - a rectal exam may be performed after the back exam.
  - Palpate all bones in a systematic fashion.
  - Examine the head for injuries, visual field cuts and wounds.
  - Assess range of motion, presence of crepitation, wounds, sensation, and motor function if the patient’s medical condition allows.
  - If abdominal injury is a possibility, a FAST, DPL or CT scan should be done to assess for intra-abdominal injury.
- **Tertiary survey**
  - The tertiary survey is performed following any initial management and/or surgery.
  - Generally speaking, the timing of the tertiary survey should be at least 24 hrs following initial presentation.

- The tertiary survey is a full head to toe exam, which should identify all previously missed injuries.
- Any point tenderness should be worked up with two orthogonal views of the involved extremity and additional advanced imaging, if warranted.

Imaging

- It is critical to obtain two orthogonal radiographic views of any injured extremity.
  - The joint above and below should also be imaged.
  - Occasionally, comparison films of the uninjured extremity are taken to aid diagnosing subtle injuries.
- In a polytrauma situation, a cervical spine series of an AP view, a lateral view with visualization to at least C7, and an open mouth odontoid view should be obtained.
  - Pseudosubluxation of the C2–C3 or C3–C4 is present in up to 40% of children on the lateral radiograph.
  - This must be distinguished from true subluxation.
- A pelvis x ray and a chest x ray should also be obtained in poly traumatized patients or patients who were involved in serious accidents (motor vehicle collision, auto vs. pedestrian, fall from height).
- CT scans are obtained if more serious internal injuries or spinal injuries are suspected on initial examination.
  - CT scan is also commonly utilized for
    - Intra-articular fractures
    - after relocation of a dislocated hip
    - acetabular fractures and sternoclavicular injuries, before and after reduction.
- MRI is used initially for spinal cord injuries without radiographic abnormality and may be obtained on a delayed basis if ligamentous or soft tissue injury is suspected clinically.

Prevention

- Injury prevention is important in pediatric populations.
- The American Academy of Pediatrics recommends against use or play with these for children:
  - trampolines
  - all terrain vehicles
  - power tools
- In addition, characteristics of playgrounds such as surface depth and zone compliance can contribute to a higher likelihood of injury.
- Car seat recommendations should be followed, and include
  - a rear-facing car seat for children under 2 years of age
  - a forward-facing car seat for toddlers and pre-school aged children
  - booster seats for school-aged children
  - a seat with lap belt for older children.
- Helmets should be worn while biking or roller blading.

Nonoperative Management

- Is more likely to occur and be successful in children than adults.
- Children must also be followed for longer than adults.
  - Late deformity can occur when the growth plate is injured.
  - If excessive shortening or lengthening because of stimulation of the physis occurs, epiphysiodesis may be considered as the child reaches the end of growth.
  - If an angular deformity occurs, it must likewise be managed.
- In general, fractures closer to the physis, and in younger children are more likely to remodel to an anatomic position.

Operative Indications

- In children, surgery is considered for
  - polytrauma
  - open fractures
  - inability to maintain satisfactory reduction by closed means.
- Single closed fractures are managed based on the natural history of the fracture.

Special Situations

- Open fractures
  - Open fractures are managed in a similar fashion to adult fractures.
  - They require IV antibiotics upon presentation.
    - Type I and II fractures receive cefazolin
    - Type III fractures receive gentamicin in addition to cefazolin
    - Farm injuries require an additional dose of penicillin.
  - Antibiotics are maintained for a period of 48 hrs.
  - Open fractures should undergo urgent irrigation and debridement upon arrival to the hospital.
    - Immediate stabilization is an option if the wound is clean and can be closed.
- **Compartment syndrome**
  - Compartment syndrome can be more difficult to assess in children than in adults and may have an atypical presentation.
  - Increasing narcotic requirement is often the earliest sign of compartment syndrome.
  - Compartment syndrome is a clinical diagnosis, and if suspected should be acted upon in an emergent fashion.
  - Surgical release of all affected compartments is indicated.

Postoperative Rehab and Expectations

- Though single traumatic injuries in children generally heal without sequelae, long-term morbidity may occur in up to one third of pediatric polytrauma patients.
  - These morbidities are generally due to head injuries or orthopedic trauma.
- The treating surgeon should treat the child as if a full recovery is anticipated.
  - Children can make dramatic improvements up to a year following head injuries, so close care is needed to prevent musculoskeletal contractures and resultant deformity.

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UPPER EXTREMITY TRAUMA

LINDSAY ANDRAS

Proximal Humerus Fractures

Pathoanatomy

These kind of fractures account for less than 5% of all pediatric fractures and are mostly seen in neonates (birth trauma) or adolescents (sports injuries). They are usually physeal or metaphyseal type fractures. The remodeling potential is high because 80% of the growth of the humerus comes from the proximal physis.

- Acceptable deformity depends on age:
  - 1–4 yrs old = 70 degrees of angulation and nearly 100% displacement
  - 5–12 yrs old = 45 degrees of angulation, less than 50% displacement
  - older than 12 yrs = 20 degrees of angulation, less than 30% displacement.

Treatment

- Most are treated closed with a sling and swathe.
  - Children younger than 4 generally require immobilization for 7–10 d while those older than 5 are immobilized for 2 to 3 wks.
- If operative treatment is necessary, it usually involves a closed reduction and pin fixation with smooth K wires or Steinman pins.
  - The axillary nerve is at risk with this procedure as it is less than 5 cm from the tip of the acromion, laterally.

Humeral Shaft Fractures

Treatment

- Most humeral shaft fractures can be treated closed as up to 40 degrees of malalignment does not appear to affect shoulder or elbow function.
  - Immobilize with a sling and swathe, hanging cast or compressive brace for 4–6 wks.
- Open treatment is reserved for
  - open fractures
  - neurovascular compromise
  - polytrauma patients with other extremity injuries.
- If the child is less than 3 yrs old, this injury may be associated with child abuse and a nonaccidental trauma work-up must be considered.
- Radial nerve injuries associated with humeral shaft fractures are usually contusions and can be treated conservatively.
- If a radial nerve palsy does not resolve in 3 mo, EMG and nerve conduction studies are indicated.

Supracondylar Fractures

Pathoanatomy

Most commonly occur in children less than 8 yrs old (after this age, elbow dislocations become more common). These fractures can be due to a fall onto an outstretched arm or to a direct blow. A fall on an outstretched arm causes an extension type fracture and is associated with (anterior interosseous nerve) AIN injury. Direct trauma causes the much more rare flexion type and is associated with ulnar nerve injury. The AIN innervates FPL and the index finger FDP. Thus, AIN injury leads to the inability to make a round OK sign with their thumb and index finger.

Differential Diagnosis

- It is imperative to assess pulse and perfusion in children with this type of fracture, as up to 20% may present with an absent radial pulse.
  - Injured arms are often splinted in extension prior to assessment, which worsens the situation.
  - If the pulse is not present, splint the arm in 30 degrees of flexion, and prepare to take the patient to the operating room immediately for a closed reduction.
  - Arteriogram is contraindicated as the level of injury is known.
  - Pulse often improves with fracture reduction.
- If there is an associated median nerve injury or if the reduction feels "rubbery," then the brachial artery may be entrapped in the fracture site.
  - In this case, open reduction is indicated if the pulse has not returned.
  - Cases in which the pulse does not return fall into 2 categories:
    1. Pink and pulseless (the hand is well perfused with brisk cap refill even though the pulse is not present), which may be observed.
    2. Poorly perfused (cool blanched or blue), which requires open exploration of the brachial artery.
- In cases with no vascular issue, operative treatment can usually wait until the light of day.
  - Exceptions to this guideline should be made for the presence of any of these:
    - marked ecchymosis
    - significant swelling
    - skin puckering by proximal fracture fragment
    - any signs of evolving compartment syndrome.

Imaging

- Radiographs: Gartland classification:
  - Type I: nondisplaced

- Type II: anterior cortex displaced but posterior cortex intact.
- These fractures are usually angulated posteriorly with the anterior humeral line NOT centered on capitellum
- Type III: complete displacement, i.e., disruption of both the anterior and posterior cortices.
- The presence of translation on the AP x-ray indicates a type III fracture.
- Type IV has also been described, but is an intraoperative diagnosis in which the fracture is shown to be unstable in both flexion and extension.

Treatment

- Treatment of type I fractures = long arm cast;
- Type II = closed reduction and percutaneous pinning (CRPP) with two lateral pins.
- Historically, type III fractures were treated with closed reduction followed by crossed pins, which resulted in a 5% incidence of iatrogenic ulnar nerve injury.
  - Crossed pins can be avoided in most cases by placing additional divergent lateral pins.
  - Assessment of reduction:
    - check that the anterior humeral line centers on the capitellum
    - Baumann angle is in valgus (more than 10 degrees)
    - and that there is substantial medial and lateral column contact.
  - Some translation can be accepted if these criteria are met.
  - Pins and/or cast are generally removed at 3 wks and range of motion exercises are initiated at that time.

Lateral Condyle Fractures

Pathoanatomy

Involve the articular surface, and thus anatomic alignment must be obtained and maintained. Previous elbow fractures that have healed in cubitus varus will be at increased risk of lateral condyle fractures. These have a high rate of complications, including: nonunion, late fracture displacement and cubitus varus.

Treatment

- Three views of the elbow are necessary for diagnosis as maximum displacement is usually seen on the internal oblique view.
- In general:
  - Fractures with less than 2 mm of displacement are treated in a long arm cast
  - 2–4 mm displacement can be treated with CRPP followed by an arthrogram to confirm that the articular surface is well reduced
  - fractures with more than 4 mm of displacement require open reduction and percutaneous pinning.
- Arthrogram is less difficult to perform if the needle is injected posteriorly, into the olecranon fossa (as opposed to the classic lateral triangle).
- During open reduction, it is crucial to avoid posterior dissection as this can damage the blood supply to the fracture fragment and result in AVN.
  - Development of AVN may present with pain and results in the fishtail deformity seen on radiographs.

Medial Epicondyle Fractures

Anatomy and Pathoanatomy

- In general, knowing the order of ossification centers of the elbow is critical to diagnosing elbow fractures and specifically, medial epicondyle fractures.
- The appearance is as follows: CRMTOL (capitellum, radial head, medial epicondyle, trochlea, olecranon, and lateral condyle).
  - If later ossification centers (trochlea/olecranon) are visible, the medial epicondyle needs to be identified.

- If it is not in its usual position, it may be incarcerated in the joint.
- Approximately 50% of these fractures are associated with an elbow dislocation.
- It is also essential to rule out concomitant fractures- isolated medial epicondyle fractures usually do NOT have a posterior fat pad present.
  - If incarcerated, it can sometimes be extracted from the joint by closed means: open elbow with valgus stress and extend wrist to put tension across the wrist flexors (Robert maneuver).

Treatment

- Indications for operative treatment are controversial.
- Results are fair with conservative treatment even in significantly displaced fractures (up to 15 mm).
- Advocates of operative treatment argue increased rate of union and the need to prevent late instability.
- Operative treatment is associated with a higher rate of ulnar nerve symptoms.

Olecranon Fractures

- More than 50% of olecranon fractures are associated with other elbow fractures.
- They are also associated with osteogenesis imperfecta.
- Minimally displaced fractures (<2 mm) are treated closed with immobilization.
- Those with more than 2 mm of displacement are treated with open reduction and suture tension band construct.

Radial Neck Fractures

Pathoanatomy

The major complication with these fractures is loss of pronation/supination. Decreased ROM is common even with appropriate treatment. Less than 30 degrees of angulation and 3 mm of translation constitutes an acceptable reduction.

Treatment

- If possible, avoid open reduction.
- Attempt a closed reduction by flexing the elbow to 90 degrees and applying pressure over the radial head while supinating/pronating the forearm.
  - If this fails, the blunt end of a K-wire or freer elevator can be inserted percutaneously and used to reduce the fracture.
  - This technique risks injury to the PIN.
- Begin ROM at 1 wk if no reduction is required and at 2–3 wks if reduction is performed.

Monteggia Fractures

Classification

- These fractures are defined by a radial head dislocation along with plastic deformation or fracture of the ulna.
- The Bado classification is used
  - Type I: most common, the radial head dislocation and ulnar fracture apex are both anterior
  - Type II: the radial head dislocation and ulnar fracture apex are both posterior/posterolateral
  - Type III: lateral/anterolateral dislocation of radial head and metaphyseal fracture of the ulna
  - Type IV: anterior dislocation of the radial head with both bone forearm fracture.

Treatment

- Reduce type I with forearm supination and elbow flexion.
  - These need to be followed weekly to check for late redislocation of

the radial head.

- The key to keeping the radial head located is reduction and stabilization of the ulna fracture.

- If the reduction is:
  - Stable: treat closed
  - Unstable:
    - for transverse or short oblique ulna fractures, treat with intramedullary fixation
    - for long oblique or comminuted fractures, treat with ORIF with plate and screws.
- Radial nerve and PIN palsies are common (especially in type III injuries).

Diaphyseal Fractures of Radius and Ulna (Both Bone Forearm Fractures)

Treatment

- These fractures account for 20% of all pediatric forearm fractures and are much less forgiving than distal fractures (as they take longer to heal and remodel less).
- Controversy exists regarding acceptable reduction.
  - However, in general, up to 20 degrees of angulation and bayonet apposition is accepted in children less than 8 yrs old
  - up to 10 degrees of angulation is accepted in 8–10 yr olds.
- Malunion can cause permanent loss of pronation/supination.
- While angular deformity can remodel, malrotation does NOT remodel.
  - There is a 5% incidence of refracture.
  - Therefore, cast immobilization is used for a minimum of 6 wks to reduce this risk.
- Assess passive ROM of fingers after all closed reductions as muscle

tethering of flexor digitorum profundus on the ulna fracture can occur.

- If the reduction is unacceptable, most are treated with closed reduction and flexible intramedullary nailing.

- Plate fixation is indicated for
  - severely comminuted fractures
  - segmental bone loss
  - adolescents nearing skeletal maturity.
  - Proper technique is crucial.
    - Specifically, during intramedullary nailing, open the fracture site after 3 attempts to pass the nail, as multiple attempts is associated with increased risk of iatrogenic compartment syndrome.

Distal Radius and Ulna Fractures

Treatment

- The key to treating these fractures is to understand the remodeling potential: it is greatest in the plane of motion (i.e., can remodel volar or dorsal angulation easier than radial inclination).
  - Up to 20 degrees of volar or dorsal angulation and 10 degrees of radioulnar deviation is accepted in young children
  - Bayonet apposition is acceptable if the child is less than 8 yrs old.
  - Malrotation will not remodel.
- Injuries to the distal radius are the most common physeal injury of childhood, but the rate of growth arrest is low (approximately 4%).
- The rate of growth arrest in ulnar physeal fractures approaches 50%.
  - Most are treated closed with a short or long arm cast (controversial). Indications for operative treatment (usually an oblique k-wire for stabilization) include:
    - unstable fractures
    - open injuries

- floating elbow
- neurovascular compromise
- soft tissue swelling/injury that prevents casting.

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PEDIATRIC LOWER EXTREMITY TRAUMA

MATTHEW D. MILEWSKI

Pediatric Femoral Neck Fractures

Classification

- These fractures are rare in children compared to adults and usually are the result of high energy mechanisms.
- Classified by the Delbet classification
  - Type I: transphyseal (AVN risk approaches 100%)
  - Type II: transcervical (AVN risk 50%)
  - Type III: basicervical/cervicothoracic (AVN risk 20–30%)
  - Type IV: intertrochanteric (AVN risk 10–15%).

Treatment

- Types I–III require emergent open reduction and internal fixation given the risk of AVN.
- Type IV usually also require open reduction and internal fixation.
- Generally fixation is required across the physis with smooth pins in young children and threaded pins or screws in older children.
  - Postoperatively they often require spica cast immobilization.
  - They can be complicated by AVN and physeal arrest.

Pediatric Femoral Shaft Fractures

Introduction

This is the most common femoral fracture pattern in children with a bimodal distribution with a peak between 2 and 4 yrs of age and then another peak in adolescence. Child abuse should be suspected in children less than 1 yr of age and those who are not yet walking.

Treatment

- Treatment is based on fracture displacement, pattern, and age of the child.
- Pavlik harness can be used for children less than 6 mo old.
- Closed reduction with spica casting can be used for children less than 6 yrs of age.
- Flexible intramedullary nailing can be used for children between 5 and 11 yrs of age who are not obese with simple fracture patterns that are not significantly shortened.
- Submuscular plating can be used in this age range for fractures with significant comminution and shortening.
- Trochanteric or lateral entry intramedullary nailing can be used in older children.
  - Piriformis nailing must always be avoided to reduce the risk of AVN.
  - External fixation can be used in open fractures and hemodynamically unstable or polytrauma patients.

Complications

- Complications can include
  - malunion (rotation does not remodel) and leg length discrepancy resulting from overgrowth (common in children less than 10 yrs of age)
  - shortening (up to 20 mm shortening is accepted in younger children at time of treatment).

Pediatric Distal Femoral Physeal Fractures

Introduction

- These fractures are most common in adolescence.
- Displaced fractures are most commonly Salter–Harris II fractures with the Thurston–Holland fragment on the compression side and the physis failing on the tension side.
  - Salter–Harris III fractures are associated with high incidence of cruciate ligament injury.
  - Some patients may also have a stretch injury to the cruciates with late knee instability.
  - Distal femoral physis is undulating, so fractures involve multiple layers of physis and lead to high rate of growth arrest.

Treatment

- Nondisplaced fractures can be treated with casting.
- Displaced and intra-articular fractures require operative fixation.
- In young children smooth pins can be placed across the physis.
- Thurston–Holland fragment fixation is common but the long lever arm distally may require additional fixation across the physis.

Pediatric Proximal Tibial Physeal Fractures

Classification

- Tibial spine or tibial tuberosity fractures are most common.
- Complete proximal tibial physeal fractures are less common but associated with high rate of vascular injury.
- Tibial spine fractures are similar to ACL ruptures.
- They can be classified (Meyers and McKeever) on lateral x-ray:
  - Type I: nondisplaced
  - Type II: anteriorly hinged
  - Type III: complete displacement.

Treatment

- Nonoperative treatment is appropriate for Type I and Type II fractures that reduce with hyperextension.
- Open reduction or arthroscopically assisted reduction and internal fixation with screws or suture fixation is needed for non-anatomically reduced Type II and Type III fractures.
- Meniscal or intramensical ligament entrapment is common.
  - Complications include
    - Arthrofibrosis
    - Loss of extension
    - Late instability.
  - Tibial tuberosity fractures are common in older adolescences.
    - The tibial tubercle and proximal tibial physis close from posterior to anterior. Intra-articular extension needs to be assessed.
  - Displaced fractures are treated with ORIF.
  - Intra-articular extension can be assessed with arthrotomy or arthroscopy.
  - Complications include compartment syndrome due to the tethering of the anterior tibial artery entering the anterior compartment proximally.

Patellar Sleeve Fractures

Pathoanatomy

While patellar fractures are less common in adolescence, unique fracture patterns, such as a patellar sleeve avulsion, are seen in this age group.

Imaging

- Radiographs may show only patella alta along with a small fragment of bone distal to the patella.
- A large sleeve of cartilage has avulsed off with the patellar tendon.
- While this most commonly involves the inferior patellar pole, it has

been described superiorly, laterally and medially (accompanying a lateral patellar dislocation).

Treatment

- Treatment is generally operative for displaced fractures with disruption of the extensor mechanism.
- The technique used to repair these fractures depends on the size of the fracture fragment:
  - For small fragments: suture and wire tension banding
  - For larger bony fragments: screw fixation is used.

Pediatric Tibial Shaft Fractures

Pathoanatomy

Tibial shaft fractures are common in this age group. Younger children often have a proximal metaphyseal fracture pattern than can present with a late valgus deformity referred to as Cozen phenomenon. Cozen phenomenon usually resolves spontaneously.

Treatment

- In general, tibial shaft fractures in children can be treated nonoperatively with long leg casting.
- Operative treatment is indicated for
  - open fractures
  - displacement of greater than 5 degrees of valgus or posterior angulation
  - displacement of greater than 10 degrees of varus or anterior angulation.
- Complications include
  - leg length discrepancies
  - angular deformity
  - compartment syndrome.

Pediatric Ankle Fractures

Classification

Distal tibial physeal injuries are very common and the second most common physeal injury. The distal tibial physis closes from central to medial and finally anterolateral. This pattern of closure results in the unique patterns: tillaux and triplane fractures. Tillaux fractures are Salter–Harris III fractures with an anterolateral epiphyseal fragment. Triplane fractures are Salter–Harris IV fractures with the epiphyseal intra-articular extension being apparent on coronal or AP views, and the metaphyseal extension being apparent on sagittal or lateral views.

Treatment

- Nondisplaced fractures can be treated with immobilization.
- More than 2 mm of intra-articular displacement requires operative intervention with closed reduction and percutaneous screw fixation or ORIF.

Complications

- Complications include
  - growth arrest (less of an issue with Tillaux and triplane fractures as the physis has already started to close)
  - angular deformity (from partial arrest or continued growth of the distal fibula)
  - post-traumatic arthritis.

Pediatric Foot Fractures

Pathoanatomy

Pediatric foot fractures are rare until patients are old enough such that the cartilaginous precursors of the tarsal bones have ossified. Phalangeal fractures are most common and generally can be treated nonoperatively unless intra-articular stepoff is significant. The base of the 5th metatarsal is the most commonly fractured metatarsal. Just as in adults, it can take longer to heal due to the poor blood supply along with the deforming force from avulsions of the peroneus brevis and abductor digiti minimi.

Treatment

- While most can still be treated nonoperatively, they may require extended immobilization or open reduction and internal fixation if conservative treatment fails.
- Talar neck and Lisfranc type fracture-dislocations can also occur in pediatric populations and generally require similar treatment patterns as adult fractures and dislocations.
- Perhaps the most devastating of pediatric foot injuries involve lawnmower injuries.
  - These can involve
    - Fracture
    - Dislocation
    - soft tissue defects
    - neurovascular injury.
  - A team-approach will be required for treatment and includes:
    - orthopaedics,
    - plastic surgery
    - vascular surgery
    - physical therapy
    - an orthotist.

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PEDIATRIC HIP DISORDERS

MICHELLE CAMERON WELBORN • AIMEE BRASHER

Developmental Dysplasia of the Hip

Introduction

The risk of developmental dysplasia of the hip (DDH) is 1/1,000 for frank dislocation. Hip subluxation is much more common at approximately 1/100 children, with 20% of cases being bilateral. Many cases of hip subluxation will resolve in the first 3–4 wks of life when the ligamentous laxity due to the influence of maternal hormones resolves and muscle tone increases.

DDH is associated with torticollis and metatarsus adductus. Risk factors include first born, breech position, oligohydramnios, and positive family history. In addition, 80% of patients are female and 60% involve the left hip. Finally, the rate of DDH is increased in Native Americans and Laplanders.

Physical Exam

- Patients with unilateral hip dislocations may have asymmetric skin folds and a positive Galeazzi sign: unequal knee heights when feet are placed on the exam table with knees flexed 90 degrees.
- Limited hip abduction may be present on the affected side, though it may not be present for several months until the laxity associated with maternal hormones resolves.
- Dislocated hips may have a positive Ortolani sign: a palpable clunk upon relocation of the hip with abduction and elevation of the femur.
- Patients with unstable hips will have a positive Barlow sign: palpable clunk as the hip dislocates with adduction and depression of the

femur.

Clinical Diagnosis

- Diagnosis is principally made by physical exam, although ultrasound is the study of choice to confirm diagnosis in children under 6 mo old.
- Radiographs are of limited use in the initial presentation as the femoral head does not ossify until 4–6 mo.
- Ossification of the femoral head may be delayed up to a year in patients with DDH.
- In older children, radiographs will demonstrate a break in Shenton line: a line drawn along the medial border of the femoral neck and the superior border of the obturator foramen.
  - In addition, hip joint lateralization may be assessed by the intersection of
    - Hilgenreiner line: a horizontal line drawn through the triradiate cartilage
    - Perkin line: a line perpendicular to Hilgenreiner line at the lateral edge of the acetabulum (Fig. 9.1).
  - In normal hips, the femoral head should be located in the inner lower quadrant.
- Wibergs Lateral Center Edge Angle (CEA) is used to assess the severity of DDH
  - It is typically done after fusion of the triradiate cartilage (average age of 12 in girls and 14 in boys).
  - This angle is measured by a line drawn from the center of the femoral head to the outer edge of the acetabular roof and a vertical line drawn through the center of the head.
    - 25 degrees: normal
    - 20 degrees: severe dysplasia
    - 16 degrees: predictive of early osteoarthritis.

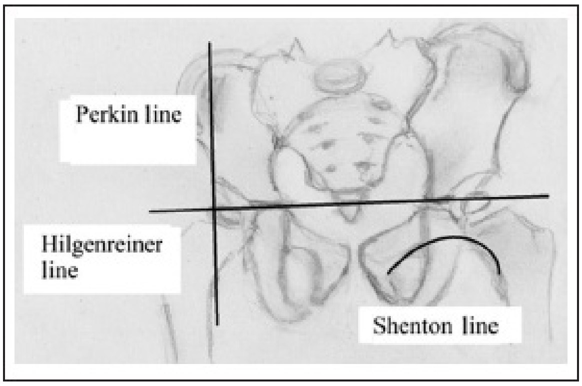

Figure 9.1 Right: Intersection of Shenton line, Perkin line, and Hilgenreiner line. Use to diagnose developmental dysplasia of the hip (DDH).

- The acetabular index is a commonly used measure in young children before the triradiate has fused,
  - It is measured by the angle between Hilgenreiner line and the acetabular inclination.
  - In an infant, the normal value averages 27.5 degrees and more than 35 degrees indicates dysplasia.
  - There is significant variation in the acetabular index and some advocate age-related standards (Fig. 9.2).

Treatment

- Left untreated, the muscles around the acetabulum contract, the acetabular roof fails to fully develop and the acetabulum fills with fibrofatty tissue or pulvinar.
  - Subluxatable hips can be monitored for 3–4 wks and many will resolve spontaneously.
  - Children that are 0–6 m old are treated in a Pavlik harness, which is a dynamic harness that places the patient in approximately 100 degrees of flexion and 60 degrees of abduction.
  - Reduction must be confirmed by ultrasound within 2–3 wks of harness placement.
  - Screen patients every 1–2 wks throughout the course of their treatment.
  - Patients should wear the harness full time for 6 wks and then part time for 6 wks, though this may be longer in children that are

older at the onset of treatment.

  - If at the end of the weaning process there is no evidence of dysplasia, the patient may end harness use and be monitored.
  - If there is some residual dysplasia, the harness is continued or if the child is walking, abduction bracing is recommended with close follow-up.
  - While the follow-up may vary, hips that are successfully reduced are typically followed with radiographs
    - every 4 mo for 12 mo
    - every 6 mo for 24 mo
    - then annually until the age of 5.
  - Approximately 2% of patients successfully treated with a Pavlik harness will go on to develop radiographic evidence of recurrent hip dysplasia and may require surgical intervention in the future.
- If the hip does not reduce by 3–4 wks, the harness should be discontinued to reduce the risk of Pavlik disease or osteonecrosis of the femoral head.
  - Hips that fail Pavlik harness treatment may be given a trial of abduction bracing.
  - If still unsuccessful, these hips require closed reduced under anesthesia in the OR and spica casting.
  - Hip positioning in the spica is critical as excessive abduction can cause osteonecrosis and excessive flexion can cause femoral nerve palsy, erosion of the pelvis superior to the acetabulum or femoral head osteonecrosis.

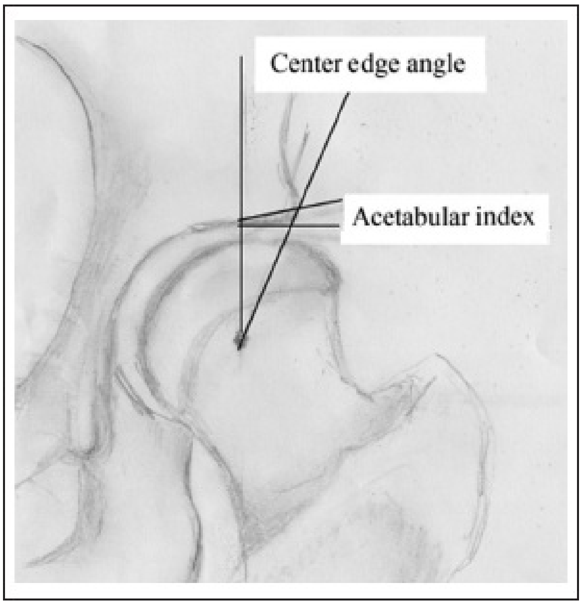

Figure 9.2 Left: Wilbergs lateral center edge angle (CEA), used to assess the severity of developmental dysplasia of the hip (DDH).

- Children 6 months to 2 yrs of age that fail closed reduction, or those older than 18 mo at presentation require an open reduction and spica casting.
- Blocks to reduction include the
  - iliopsoas tendon
  - pulvinar, inferomedial hip capsule
  - transverse acetabular ligament
  - an inverted labrum.
- All patients should be casted for at least 12 wks after reduction.
- Patients that are over 2 yrs old should have either femoral or pelvic osteotomies as is indicated by their particular pathology.
- Reduction is generally contraindicated in children with bilateral DDH over 5 yrs or unilateral DDH over 8 yrs.

Coxa Vara

Introduction

Consists of decreased neck shaft angle with ⅓–½ being bilateral. Typically the cervicofemoral angle is 35 degrees in infancy and increases to 45 degrees by skeletal maturity. Coxa vara refers to an increase in that cervicofemoral angle or a decrease in the angle of inclination. Coxa vara can be congenital, developmental, dysplastic or traumatic. Congenital coxa vara is associated with congenitally short femur, external rotation of the femur and genu valgum.

The deformity does NOT spontaneously resolve. The percentage of shortening remains constant from infancy to adulthood. Dysplastic coxa vara is associated with vitamin D-resistant rickets, fibrous dysplasia, generalized dysplasias, Paget disease and osteopetrosis. Dysplastic forms often benefit from surgical intervention.

Traumatic coxa vara develops after injuries to the proximal femoral growth plate, such as fractures, AVN, infection or Perthes disease. In these cases, the greater trochanter continues to grow while the physis does not, resulting in coxa vara.

Physical Exam

- Patients may present with a waddling gait or a painless limp.

Imaging

- Diagnosis is made by AP pelvis radiographs.
- Hilgenreiner angle is the angle between Hilgenreiner line and a line through the proximal femoral physis.
  - Patients with a Hilgenreiner angle
    - < 45 degrees tend to spontaneously correct.
    - of 45–60 degrees should be observed as many may also correct spontaneously
    - 60 degrees usually require surgery.

Treatment

- Surgical treatment is required when the deformity is progressive or associated with leg length discrepancy or limp.
- This entails a proximal femoral valgus osteotomy with or without derotation.
- Traumatic forms are often treated with epiphysiodesis or advancement of the greater trochanter.

Legg Calve Perthes Disease

Introduction

Most commonly presents in patients 4–8 yrs old with knee pain and a limp. Boys are 4–5 times more commonly affected than girls, 10–20% are bilateral, and it occurs in roughly 0.2–19.1/100,000. The exact etiology is unknown, though it is associated with a positive family history and low birth weight.

Physical Exam

- Patients may demonstrate a Trendelenburg gait and limited ROM of the hip, depending on stage.
- The first sign is often decreased hip IR on the affected side.
- Chronically, there may be wasting of the muscles of the thigh and a slight limb length discrepancy.

Classification

- The most commonly used classification systems are the Catterall and the Lateral Pillar Classifications.
- The Catterall system is
  - graded from I–IV
  - and is based on which portion of the head is involved- anterior, central, lateral, and metaphyseal.
    - Grade I: no collapse and anterior epiphysis involvement only.
    - Grade II: more anterior involvement with collapse of the femoral head and sequestration of the collapsed area.
    - Grade III: only a small area of the epiphysis is not involved, with central collapse and some preservation of the medial and lateral sides.
      - Generalized metaphyseal changes are also seen.
    - Grade IV: whole head involvement with extensive metaphyseal changes.
  - Catterall risk signs are poor prognostic indicators. These risk signs include:

- lateral collapse resulting in a horizontal growth plate
    - the gage sign, which is a v-shaped sequestrum
    - calcifications lateral to the growth plate
    - lateral subluxation of the femoral head.
- The Lateral Pillar Classification
  - divides the head into three pillars: medial, central and lateral,
  - is graded based on the extent of pillar height loss.
    - Grade A: no lateral pillar involvement and no collapse.
    - Grade B: less than 50% loss of height.
    - Grade B-C: there is a thin, poorly ossified lateral pillar with 50% loss of height.
    - Grade C: less than 50% of the lateral pillar is retained.
  - This theory is based on the idea that the lateral pillar is fundamental for the support of the femoral head and that its loss destabilizes the head.
  - Disease progression is determined radiographically.
    - Waldenstrom described four stages of progression.
      - Stage 1: initial increased density and physeal blurring.
      - Stage 2: head fragmentation and collapse.
      - Stage 3: reossification begins centrally.
      - Stage 4: healed.

Treatment

- Several different treatment algorithms based on a combination of factors, including:
  - the patient's age
  - their Catterall or Lateral Pillar classification
  - their stage of disease.
- Patients who present in the earlier stages are treated with
  - rest

  - anti-inflammatories
  - physical therapy.
- In more severe cases or in older children, early intervention may be attempted with containment procedures to redirect the head and minimize its fragmentation.
- Once the head has healed, other interventions may be performed to deal with the disease sequel, such as
  - head reduction osteotomies
  - osteoplasty
  - trochanteric advancement
  - acetabular or femoral osteotomies.

Slipped Capital Femoral Epiphysis

Introduction

Slipped capital femoral epiphysis (SCFE) is basically a Salter–Harris type 1 fracture through the hypertrophic zone of the proximal femoral physis. The deformity results from the femoral head remaining in the acetabulum as the neck displaces anteriorly and externally rotates.

Epidemiology

- It occurs in 0.2–10/100,000 patients and most often presents during periods of rapid growth, in girls aged 10–13 and boys aged 12–15.
- The incidence is increased in
  - African Americans
  - children who are obese,
  - in those with endocrine disorders such as hypothyroidism and hypopituitarism.
- The presence of SCFE in one hip significantly increases the risk of a contralateral slip.
- Children younger than 10 should have an endocrine workup.

Presentation

- At initial presentation, the contralateral limb must be carefully examined and radiographed as 18–50% of cases are bilateral.
- Patients with stable slips are able to ambulate with or without crutches.
- Patients with unstable slips are unable to bear any weight, or ambulate on the affected limb.
- Slips can be chronic, acute or acute-on-chronic.
- Acute and acute-on-chronic are often precipitated by trauma.

Physical Exam

- Patients often demonstrate an externally rotated gait and thigh atrophy.
  - They will complain of pain in their hip, thigh or knee.
  - Obligate external rotation with hip flexion is pathognomic.

Imaging

- Diagnosis is made with AP and frog lateral pelvis x-rays.
- Radiographs of the pelvis should always be taken with a child that presents with knee pain as hip pain is commonly referred to the knee.
- Klein line, a line drawn along the anterosuperior femoral neck, is performed on the AP and frog lateral pelvis radiographs.
- In SCFE, Klein line will be flush with the epiphysis or the epiphysis will be below it.
- Frog leg lateral view is necessary as subtle slips may be present on this view alone.
- The slip angle is measured by the degree of displacement of the epiphysis with respect to the metaphysis
  - $<$ ⅓ represents mild disease
  - ⅓–½ moderate disease
  - $>$ ½ severe disease.

Treatment

- Although treatment remains controversial, slips are typically treated with in situ cannulated screw fixation.
  - Some surgeons recommend gentle closed vs. open reduction with screw fixation for acute unstable slips in order to decrease the rate of malunion.
    - However, slip reduction is associated with more risks, particularly the significantly increased risk of AVN.
    - One screw is recommended so as to minimize the risk of joint penetration and subsequent osteonecrosis.
    - Highly unstable slips may require two screws.
  - Many advocate hip aspiration or capsulotomy at the time of pinning to decompress the hematoma and thus decrease the intra-capsular pressure.
  - Timing of surgery is also controversial, though most agree that surgery should be performed promptly and ideally within one day of presentation after an acute unstable slip.
  - Postoperatively, patients with stable slips may be weight bearing as tolerated a day or two after surgery, whereas patients with acute unstable slips are non-weight bearing for 6–8 wks.
  - Acute unstable slips have a high risk of AVN ranging from 2–64%, whereas the risk is close to 0% in stable SCFE.
  - After the slip has healed, osteotomies of the femoral neck may be performed to improve femoral head alignment and to minimize femoroacetabular impingement.
  - The location of the osteotomy is controversial:
    - base of the head osteotomies result in greater correction, but also higher risk of AVN
    - base of the neck or intertrochanteric osteotomies provide less correction but less AVN risk.

Femoral Anteversion

Introduction

Femoral anteversion consists of increased internal rotation of the femur. It most often presents in 3–6 yr olds and is more common in females. When associated with internal tibial torsion, patellar maltracking or patellofemoral problems may also be present.

Physical Exam

- Patients often sit in the "W" position and ambulate with an internal foot progression angle or "pigeon toed" gait.
- Hip rotation is measured prone with the knees flexed to 90 degrees.
- These patients demonstrate excessive internal rotation of the hips.

Clinical Diagnosis

- Clinical diagnosis is based on the angular difference between the axis of the femoral neck and the transcondylar axis of the knee.
- Determine this by palpating the most prominent aspect of the greater trochanter and measuring its position with respect to the position of the tibial shaft.
- Normal femoral anteversion is 30–40 degrees at birth and decreases to an average of 8–14 degrees in adults.

Treatment

- 80% will spontaneously correct by age 10.
- Torsion level is based on degree of internal rotation:
  - Mild torsion: between 70 and 80 degrees
  - Moderate: 80–90 degrees
  - Severe: >90 degrees.
- More severe, symptomatic cases may be treated with intertrochanteric derotational osteotomies after the age of 10.

Proximal Femoral Focal Deficiency

Introduction

Proximal femoral focal deficiency is a very rare disorder that affects 1/52,000 live births, and is bilateral in 10–15% of patients. It is commonly associated with other musculoskeletal abnormalities with 50% of ipsilateral and 26% of contralateral limbs having abnormalities. These include fibular hemimelia (most common), patellar absence, genu valgum, unstable knees, foot malformations, ulnar defects, and Pierre Robin disease.

It must be differentiated from congenital hypoplastic femur, in which the hip and knee are functional (unlike in PFFD). Histologically, the proximal femoral growth plate, specifically, the proliferative zone, is disorganized with flattened cells. It is associated with maternal Thalidomide use.

Physical Exam

- Patients have an extremely short femur with hip and knee held in flexion at birth.
- Furthermore, there are often flexion, abduction, external rotation contractures of the hip and flexion contractures of the knee.
- There may be a high riding patella.
- An inadequate abductor mechanism leads to a Trendelenburg gait in patients who ambulate.

Diagnosis

- The diagnosis ranges from mild bowing to absence of the entire proximal part of the femur and the acetabulum.
- The femur is retroverted and the lateral femoral condyle is hypoplastic.
- There are several classification systems including the Aitken classification, which classifies types A–D.
  - Type A: sufficient acetabular coverage, coxa vara, a short femoral shaft and a subtrochanteric pseudarthrosis.
  - Type B: sufficient acetabular coverage and femoral head, delayed ossification of the femoral head, no connection between the femoral head and shaft, severe varus deformities and possible pseudarthrosis.
  - Type C: severely dysplastic acetabulum, no femoral head, severely shortened femur.

- Type D: no femoral head, severe dysplasia of the acetabulum, severely shortened femur.
- Gillespie classification is divided into types 1 and 2, where the femur can be made functional in type 1 but not in type 2.

Treatment

- Mild cases may require valgus osteotomies and femoral lengthening with contralateral epiphysiodesis.
- More severe cases may require rotationplasty, megaprosthesis, or Symes amputation with knee fusion and prosthetic fitting.
- Megaprostheses have a very high failure rate and placement requires a stable hip joint.
- Rotationplasty is durable and associated with increased time upright.

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PEDIATRIC KNEE DISORDERS

MICHELLE CAMERON WELBORN • AIMEE BRASHER

Blount Disease

Introduction

- Blount disease is divided into three different types, infantile, juvenile, and adolescent, which are based upon the patient's age when first diagnosed.
  - The infantile form presents between 1 and 3 yrs, is commonly bilateral and typically results in the most severe tibial deformities of the three.
  - The juvenile form presents between 4 and 10 yrs.
  - The adolescent form presents after 11 yrs and these patients often have significant varus deformity of the femur.
- Ultimately, all forms result in a complex 3D deformity of the proximal tibia, which consists of varus, procurvatum, and medial physeal depression.

Etiology

- The etiology of Blount disease is currently unknown, though all types are significantly increased in African-Americans and patients with increased weight to height ratios, most exceeding the ninety-fifth percentile for their age.
- Recently, it has been determined that the adolescent form is seven times more common in patients with vitamin D deficiency.
- Lastly, Blount must be distinguished from physiologic varus, which peaks between 1 and 3 yrs of age and resolves spontaneously.

Physical Exam

- Patients are typically very obese.
- Significant genu varum is noted, predominately of tibial origin especially in the younger patients.
- Patients with more severe deformity demonstrate a lateral thrust with gait.

Diagnosis

- The diagnosis is primarily made based upon radiographs.
  - The AP hip-to-ankle radiograph demonstrates a varus mechanical axis.
  - The AP knee radiograph shows medial tibial metaphyseal beaking, which is especially prominent with the infantile form, and medial plateau depression.
  - A metaphyseal diaphyseal angle, which consists of a line drawn perpendicular to the mechanical axis of the tibial shaft and another parallel to the proximal tibial metaphysis, greater than 16 degrees is considered diagnostic.
- The degree of severity is based on the Langenskiöld classification, which is derived from AP radiographs
  - It grades the deformity from I–VI based on the degree of metaphyseal beaking, joint line depression, and fragmentation of the medial tibial metaphysis.
    - Stage I: irregularity of the proximal tibial physis and minimal beaking.
    - Stage II: mild sloping of the medial physis and increased beaking.
    - Stage III: increased medial metaphyseal depression without epiphyseal depression.
    - Stage IV: depressed epiphysis.
    - Stage V: significant medial joint line depression.
    - Stage VI: medial physeal bony bar formation.

Treatment

- Treatment is typically based on age and severity of disease.

- Patients younger than 3 yrs old are initially treated with a KAFO (knee—ankle–foot orthosis).
- Patients with lower level Langenskiöld classifications are frequently treated with figure of eight plates or lateral physeal stapling.
- In patients with moderate to severe disease, valgus or dome osteotomies with or without external fixation are often performed to correct the varus alignment.
  - These may be combined with medial opening wedge osteotomies to correct the joint line depression if it is severe.
- Currently there is no gold standard for the treatment of Blount disease.
- All forms of treatment are unfortunately associated with high recurrence rates, especially if performed in very young patients.

Valgus Deformity

Introduction

Genu valgum is a common deformity of the knee. It is classified as physiologic, idiopathic or pathologic. Most resolve spontaneously as physiologic valgus peaks between 3 and 6 yrs of age.

Etiology

- Idiopathic forms primarily involve the distal femoral metaphysis.
- Pathologic forms may be associated with
  - Rickets
  - Pseudoachondroplasia
  - mucopolysaccharidosis
  - Ellis–van Creveld syndrome
  - osteopetrosis
  - Ollier disease
  - Multiple Hereditary Exostosis (MHE).
    - 70–98% of patients with MHE have tibial involvement

    - 8–33% have genu valgum.
    - Patients with MHE additionally tend to have disproportionately shortened fibulas.

Physical Exam

- Patients often present to clinic with anterior knee pain.
- They are knock-kneed and the valgus angulation may be predominately tibial or femoral depending on the etiology.
- More severe cases are associated with a circumducting gait or a medial thrust with gait.
- Patients may also have patellofemoral instability or medial knee laxity.

Diagnosis

- Full-length, weight-bearing lower limb films are used to assess the degree and location of deformity.
- Several different radiographic measures have been employed to determine the degree of severity including:
  - the mechanical axis deviation (a line drawn from the center of the femoral head to the ankle, which should fall within the central 50% of a normal knee)
  - the tibial-femoral angle (the angle formed between a line drawn from the ASIS to center of the patella to the center of the ankle joint.
    - This angle is approximately
      - 15 degrees of varus at birth,
      - overcorrects to 10–12 degrees of valgus at 1.5–2 yrs of age,
      - settles at 5–6 degrees of valgus at 7 yrs of age and remains roughly constant to adulthood);
      - the lateral distal femoral angle (the angle formed by a line drawn from the center of the femoral head to the midpoint between the femoral condyles and one parallel to the distal femoral condyles, which averages 85–90 degrees);
      - the medial proximal tibial angle (the angle formed by a line

drawn down the tibial shaft and one parallel to the tibial plateau, which is approximately 87 degrees).

Treatment

- Surgical correction should be considered when the intermalleolar distance (which is the distance between the medial malleoli in a standing patient when their knees are touching) is 8 cm or greater.
- In young patients, figure of eight plate, stapling or epiphysiodesis may be used to slowly correct the deformity.
- Timing is important so as to prevent overcorrection and to help minimize any growth retardation.
  - Thus, treatment is often performed later in idiopathic patients where the deformity tends to progress more slowly.
- Pathologic deformities typically progress more rapidly and thus require earlier correction.
- Most patients treated with figure of eight plating or stapling require hardware removal once corrected.
  - Failure to remove the hardware may lead to overcorrection, hardware breakage, hardware migration, or symptomatic hardware.
- Despite these complications, even patients with severe deformity may benefit from figure of eight plates, stapling, or epiphysiodesis to help minimize the deformity, making subsequent osteotomies less difficult to perform.
  - These patients require close follow up until skeletal maturity in order to assess for recurrent deformity, over correction, or limb length discrepancy.
  - Patients with recurrent deformity or those untreated at skeletal maturity may require osteotomies to achieve acceptable correction of the deformity.

Congenital Knee Dislocations

Introduction

Congenital knee dislocations are rare, occurring in 0.17/1,000 live births. 40–100% have associated musculoskeletal abnormalities, including DDH, which is usually ipsilateral, and club foot.

Etiology

- These types of dislocations may be idiopathic or pathologic.
- Pathologic forms may be caused by
  - arthrogryposis
  - Larsen disease
  - Ehlers Danlos
  - oligohydramnios
  - extended breech position.
- They are primarily caused by fibrous contractures of the quadriceps and the anterior knee capsule.
- It is associated with attenuation or absence of the cruciate ligaments of the knee.

Physical Exam

- Patients present at birth with irreducible genu recurvatum.
- They have tight, contracted knee extensors preventing knee flexion.
- The femoral condyles may be palpable in the popliteal fossa.

Diagnosis

- Diagnosis is typically based on clinical exam findings
- Knee radiographs or ultrasound may be used confirm the diagnosis.

Treatment

- Closed reduction is ideally performed within 24 hrs of delivery by placing traction on the limb and gently translating the femur anteriorly.
- Once the femoral condyles engage the tibial plateau, gently flex the knee and cast.
- Sequential casting should be performed every 1–2 wks until 90

degrees of flexion is achieved.

- If conservative methods fail, quadriceps lengthening and capsulotomies are performed, followed by reduction and casting.
- When associated with DDH, the knee dislocation is treated first as the Pavlik harness cannot be properly applied until the knee obtains 90 degrees of flexion.

Congenital Patella Dislocation

Introduction

- Congenital patella dislocations are very rare.
- Far more common are progressive patella dislocations, which are associated with:
  - arthrogryposis
  - Down syndrome
  - Kabuki
  - Ellis–Van Creveld
  - nail-patella syndromes
  - as their dislocation occurs after birth and are thus developmental and are not congenital.
- Congenital patella dislocations have many associated limb abnormalities including
  - knee contractures
  - femorotibial rotatory disorders
  - genu valgum
  - external tibial torsion
  - calcaneovalgus
  - talipes equinovarus
  - congenital vertical talus

Physical Exam

- Frequently, the initial presentation is one of gait disturbance.
- The patella is underdeveloped, difficult to palpate and lies lateral to the lateral femoral condyle.
- It is often immobile and adherent to the femur.
- The quadriceps is short, contracted and deviated laterally.
- The IT band is thick and tubular and inserts on the lateral condyle deep to the patella, rather than on Gerdy tubercle.
- The dislocated extensor mechanism is inadequate, leading to lack of active knee extension beyond 90 degrees.

Diagnosis

- Congenital patella dislocations can be difficult to diagnose because the patella does not ossify until 3–5 yrs of age.
- Ultrasound or MRI can be utilized to make the diagnosis in young children; CT is rarely used.
- In older children, sunrise views of the knee will demonstrate an empty shallow notch and a laterally positioned patella.

Treatment

- Patellar dislocations are treated with
  - extensive release of quadriceps adhesions,
  - lateral release,
  - medial plication with or without derotation
  - or v-y lengthening of the quadriceps tendon.
- The associated knee flexion contractures are subsequently treated with serial casting.
- Treatment should be performed early to minimize the growth changes associated with a dislocated patella and to prevent deformity progression.

Osgood Schlatter—tibial Osteochondrosis

Introduction

- Osgood Schlatter is a common disorder that is present in up to 21% of athletic boys compared with 4.5% of nonathletic controls, with 20–30% of cases being bilateral.
- It is a traction apophysitis caused by repetitive microtrauma to the tibial tubercle by the pull of the patellar tendon.
- It typically occurs at times of growth spurts:
  - 12–15 yrs of age in boys
  - 8–12 yrs in girls.

Physical Exam

- Patients have tenderness to palpation over the tibial tubercle, which may be prominent or swollen.

Diagnosis

- Diagnosis is based on clinical exam.
- AP and Lateral radiographs demonstrate
  - tibial tubercle prominence
  - irregularity of the apophysis
  - separation of the tibial tuberosity early in the disease with fragmentation appearing in later stages.

Treatment

- Conservative treatment typically begins with activity modification until symptoms resolve.
  - In particularly severe cases, immobilization in a knee immobilizer or cylinder cast may be employed.
  - This is followed by therapy to restore flexibility and strength of the quadriceps.
- Patients may return to sport once their strength is adequate.
- It may take up to 12–24 mo for complete resolution of symptoms and symptoms may persist until the physis closes.

Sindig Larsen Johansson Syndrome

Introduction

Sindig Larsen Johansson syndrome is a patellar osteochondrosis due to an overuse traction apophysitis of the patellar tendon at its attachment site on the patella. Onset is typically between the ages 10 and 12.

Physical Exam

- Patients have tenderness to palpation over the inferior pole of the patella.
- Chronic cases may have palpable inferior pole calcifications.

Diagnosis

- AP and lateral radiographs of the knee demonstrate calcifications of the proximal attachment site of the patellar tendon.
- The patellar tendon may appear to be partially avulsed.

Treatment

- Most cases resolve within 1 yr.
- Treatment consists primarily of rest and activity modification, followed by quad strengthening, stretching and cross training.

Tibial Torsion

Introduction

- Internal tibial torsion is the most common cause of in-toeing and is thought to be secondary to intrauterine molding.
- It is often bilateral and ⅓ of patients have metatarsus adductus.
  - Normally the tibia has 5 degrees of internal tibial torsion at birth, which progresses to 15 degrees of external tibial torsion at maturity.
  - Thus, internal tibial torsion corrects over time, whereas external tibial torsion worsens over time.

- External tibial torsion causes out-toeing and usually presents in toddlers.

Physical Exam

- There is frequently increased foot progression angle during gait, which is the angle formed between the long axis of the foot and a straight line drawn along the path the patient is walking.
- It is associated with a high degree of variability and the normal ranges from 3 degrees of internal tibial torsion to 20 degrees of external tibial torsion.
- There is also increased thigh foot angle, which is the angle made between the thigh and the foot measured prone with the knee flexed to 90 degrees.
- The normal thigh foot angle ranges from 5 degrees of internal tibial torsion to 30 degrees of external tibial torsion.

Diagnosis

- Diagnosis is typically made on clinical exam,
- though standing full length radiographs may be employed to determine if there is any other associated pathology.

Treatment

- Most cases typically resolve spontaneously and thus are rarely treated surgically.
- Patients that deviate from the mean by more than two standard deviations may be considered for surgical intervention if they are symptomatic.
- Older patients with greater than 10 degrees of internal tibial torsion or greater than 35 degrees of external tibial torsion may undergo supramalleolar osteotomy to correct the rotation.

Congenital Pseudarthrosis of the Tibia

Introduction

- Congenital pseudarthrosis of the tibia is a rare disorder occurring in

1/150,000 live births.

- It is associated with neurofibromatosis type 1 in 55% of cases and the fibula is affected in ⅓–½ of cases.
- It is characterized by a pseudarthrosis at birth or a pathologic fracture through bowed bone.
- There are two main forms:
  - primary pseudarthrosis, which is present at birth
  - secondary pseudarthrosis in which the pathologic fracture occurs when the child begins to ambulate.

Physical Exam

- Patients have anterolateral angulation of the tibia.
- The tibia is shortened and the foot is often inverted.
- When a fracture is present, there may be palpable callus, crepitus or tenderness to palpation.

Diagnosis

- AP and lateral tibial radiographs demonstrate the deformity.
- Radiographs demonstrate an atrophic or hypertrophic pseudarthrosis.
- The tibia may demonstrate cystic or dystrophic changes.

Classification

- The most commonly used classification system for anterior bowing is the Crawford Classification.
  - Type I: narrow medulla.
  - Type II: sclerotic narrow medulla.
  - Type III: cystic changes.
  - Type IV: fracture or pseudarthrosis.

Treatment

- Treatment remains controversial.
- The goal is to resect the fibrous portion of the tibia with or without

resection of the fibula (if it is involved), followed by stabilization of the tibia with either intramedullary nailing, Ilizarov fixation, or free vascularized fibula grafting.

- Amputation is considered if there are significant foot deformities, limb length discrepancy or failure to achieve bony union.
- Ankle valgus is a frequent complication of the disease that may result in asymmetric growth.
  - Furthermore, ankle valgus can increase the refracture rate of the tibia as well as causing tibiotarsal instability.
- Overall, there is a high refracture rate of the tibia and outcomes are poorer if the tibia is not united by age 6.
- Limb length discrepancies are common and frequently require contralateral epiphysiodesis or limb lengthening once the tibia has united and the final discrepancy can be estimated.

Congenital Posteromedial Bowing

Introduction

Congenital posteromedial bowing is a benign condition present at birth that more commonly affects the left side and tends to correct spontaneously. Ankle calcaneovalgus deformity, which may be present, also spontaneously resolves. Posteromedial bowing is associated with limb shortening that does not correct over time. The degree of limb shortening correlates with the severity of bowing.

Physical Exam

- There is posteromedial bowing of the tibia, limited ankle dorsiflexion or plantar flexion weakness, which is related to the severity of the leg-length discrepancy.
- The foot may be smaller on the affected side.

Diagnosis

- AP and Lateral x-rays are used to determine the degree of diaphyseal bowing.
- The two most commonly used grading systems are Malhorta and

Shapiro.

- Malhorta grading system
  - ranges from 1–3
  - is based on position of the growth plate of the tibia versus the fibula as the fibular physis moves more proximal.
  - Normally the distal fibular physis is at the level of the tibial plafond.
    - Grade 1: the fibular physis is above the plafond but below the tibial physis.
    - Grade 2: the fibular and tibial physes are at the same level.
    - Grade 3: the fibular physis is above the tibial physis.
- Shapiro grading system
  - is based on the degree of wedging of the distal tibial epiphysis,
  - normal demonstrates no wedging.
    - Grade 1: mild wedging of the central portion of the distal tibial epiphysis, without significant involvement of the lateral part of the epiphysis.
    - Grade 2: moderate wedging, with the distal tibial epiphysis slanted into the physis at its lateral edge.
    - Grade 3: severe wedging with the distal tibial epiphysis slanted into the lateral ⅓ of the physis.

Treatment

- Treatment of congenital posteromedial bowing is threefold: first correct any residual bowing, second correct any limb length discrepancy and third correct any remaining ankle calcaneovalgus.
- Corrective osteotomy is performed if bowing is
  - $>$25 degrees in both planes between 1.5 and 3 years or
  - $>$20 degrees in either plane over the age of 3 years.
- Limb length discrepancy is treated with epiphysiodesis as is unresolved ankle calcaneovalgus (hemiepiphysiodesis).

Tibia Hemimelia

Introduction

- Tibial hemimelia is a rare congenital abnormality that occurs in approximately 1/1,000,000 live births and is associated with absence or deficiency of the tibia.
- It is bilateral in approximately 30% of cases.
- The fibula tends to be partially or completely intact.
- 75% of patients have associated anatomic abnormalities including
  - congenital hip dislocation
  - proximal femoral focal deficiency
  - coxa valga
  - knee instability
  - limb length discrepancy
  - equinovarus foot
  - subtalar and midfoot fusions
  - syndactyly of the hand or foot
  - hypoplastic or absent digits of the hand or foot
  - lobster claw hand
  - radial dysplasia
  - hypoplastic vertebra or hemivertebrae
  - hypospadias
  - cleft palate
  - imperforate anus
- It may be associated with autosomal dominant disorders, which cause split hand deformities, femoral bifurcation or defects of the ulna.

Physical Exam

- The lower limb is bowed and shortened, and the foot is held in rigid supination.

- Knee instability may be present.

Diagnosis

- The diagnosis is made radiographically
- It is categorized via Jones classification.
  - Type 1a: absent tibia with a hypoplastic distal femur.
  - Type 1b: rudimentary tibia with a near normal femur.
  - Type 2: near normal proximal tibia.
  - Type 3: amorphous segment of tibia either proximally or distally.
  - Type 4: primarily distal deficiency and ankle diastasis.

Treatment

- More severe forms are treated with knee disarticulation.
- Centralization of the fibula under the femoral condyles (Brown Procedure) is frequently associated with additional procedures as there is often significant knee instability.
  - Moderate to severe forms may be treated with synostosis of the tibia anlage to the fibula.
  - Less severe forms are treated with Syme or Chopart amputations.

Fibular Hemimelia

Introduction

- Fibular hemimelia is a rare congenital anomaly consisting of fibular deficiency or absence.
- It is the most common form of long bone absence or hypoplasia, is typically unilateral and occurs sporadically, with an increased incidence in boys versus girls.
- It is often associated with
  - deficiency of the lateral aspect of the foot and the distal tibia
  - proximal femoral focal deficiency
  - femoral hypoplasia

    - tarsal coalition
    - limb length discrepancy
    - anteromedial bowing of the tibia
    - ball and socket ankle
    - absent tarsal bones or foot rays
- Up to 95% of patients with fibular hemimelia have an absent ACL.

Physical Exam

- Most patients have clinical evidence of ACL absence.
- They may also have
    - femoral retroversion
    - patellar instability
    - knee instability
    - anteromedial tibial bowing
    - foot abnormalities

Diagnosis

- Radiographs demonstrate the deficiency or absence of the fibula and a wedge shaped distal tibial physis.
- There are several different classification systems.
    - The one derived by Achterman and Kalamchi is based on fibular morphology:
        - Type Ia: mild shortening secondary to a proximal fibular epiphysis that is distal and a distal fibular epiphysis that is proximal, with significant ankle valgus.
        - Type Ib: more severe shortening of the fibula with associated tibial shortening.
        - Type II: absent fibula.
    - Stanitski and Stanitski developed an expanded classification system that takes into account
        - the morphology of the fibula and the tibiotalar joint,

- the presence of tarsal coalition
- the number of rays in addition to the size of the fibula.
  - Fibula I: near normal fibula.
  - Fibula II: small fibula.
  - Fibula III: complete fibular absence.
- The tibiotalar joint morphology is then classified as: horizontal, valgus or spherical.
- Presence or absence of tarsal coalition is documented, along with the number of rays present, 1–5.

Treatment

- Treatment is based on the extent of foot deformity with Syme amputation used for patients with fewer than three rays.
- Posteromedial soft tissue release, resection of the fibular anlage, Achilles, and peroneal tendon lengthening and limb lengthening are commonly performed in patients with three or more rays.
- In more severe cases, tibiotalar ankle arthrodesis is performed as well.
- Patients often require orthotics in addition to surgical intervention.

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FOOT DISORDERS

ABIGAIL ALLEN • JANAY MCKIE

General Evaluation

- Observe skin on the sole of the foot
  - Are there any signs of excessive loading (e.g., callous)?
- Observe feet sitting and standing positions (include toe standing, if possible)
  - Evaluate the position of the heel (valgus is normal with standing)
  - Evaluate the longitudinal arch
- Assess ROM of toes, subtalar and ankle joints
- Palpate for points of maximal tenderness

Flatfoot

Differential Diagnosis

- Pes planus
- Calcaneal valgus foot
- Congenital vertical talus
- Tarsal coalition

Pes Planus (Flat Foot)

Etiology

- It is important to determine a flexible versus rigid deformity.
- A flexible flat foot is one in which the arch becomes apparent when the foot is made non-weight bearing (sitting) or when standing on

toes.

Treatment

- If the foot is flexible and asymptomatic, then no treatment is necessary.
- If the foot is flexible and symptomatic, then treatment should be geared towards the symptoms and not the deformity.
- Symptoms can be attributed to tight heel cords, accessory bones or other conditions.
  - In this situation, make sure weight bearing films are obtained.
  - Add external oblique view if accessory navicular is suspected.
  - Add internal oblique view if calcaneonavicular coalition is suspected.
- Surgery is the last option after nonoperative measures fail.
  - Surgical options include
    - gastrocnemius recession
    - subtalar arthrodesis
    - lateral column lengthening osteotomy
    - combined osteotomies of the hindfoot and midfoot based on the extent of soft tissue or bony deformity contributing to the symptomatic flexible flat foot deformity.
- See below for rigid flatfoot deformity discussion.

Calcaneal Valgus Foot

Presentation

- The patient presenting with calcaneal valgus foot deformity has their forefoot lying against the anterolateral tibia.
- This deformity is usually secondary to intra-uterine positioning and is recognized at birth.

Treatment

- Stretching exercises to pull the foot back into anatomic position (3 times a day) are the usual treatment with the expectation that the foot deformity will resolve over 3–6 mo.
- If stretching exercises fail, investigate for other diagnoses.

Congenital Vertical Talus (CVT)

Etiology

- CVT is an irreducible dorsal dislocation of the navicular bone on the talus.
- In approximately 50% of patients, it is associated with
  - spina bifida
  - arthrogryposis
  - sacral agenesis
  - diastematomyelia
  - chromosomal disorders

Presentation

- Patients present with a rigid flatfoot deformity with a convexity noted over the medial aspect of the foot.
- This convexity is the talar head that contributes to the palpable convexity at the plantar medial aspect of the foot.
- This deformity is termed a “rocker bottom” deformity.

Imaging

- The key finding on the lateral radiograph of the foot is a vertical talus in relation to the tibia.
- Also, a lateral plantar flexion view is helpful to distinguish true congenital vertical talus from an oblique talus.
- Because the navicular bone does not ossify until the child is approximately three years old, use the talar axis in relation to the first metatarsal, (instead of to the navicular).
- If the talar axis lines up with the first metatarsal in the plantar flexion lateral, it is an oblique talus.
  - If it does not, it is a congenital vertical talus.

Treatment

- There is no role for solely nonoperative treatment.
- Treatment consists of a combination of serial casting followed by surgery.

- Treatment options include reverse Ponseti casting technique, followed by open reduction and pinning of the talonavicular joint.
- Soft tissue releases are performed if needed.
- Prior to treatment, syndromes associated with this foot deformity must be ruled out.
- Oblique talus usually needs no treatment besides stretching.

Tarsal Coalition

Introduction

- Tarsal coalitions are fusions between the tarsal bones that lead to loss of inversion and eversion motion of the foot.
- These fusions can cause stress on adjacent joints over time and lead to pain after being clinically silent.
- Coalitions may involve more than one joint.
- The most common coalitions are calcaneonavicular and talocalcaneal coalitions.
  - However, other coalitions can exist.
  - Coalitions are bilateral in 50–60% of patients and they can be inherited in an autosomal dominant pattern.

Presentation

- The patient presenting with a tarsal coalition is usually an adolescent: 8–12 yr olds for calcaneonavicular and older than 12 yrs for subtalar coalitions.
- Patients have a history of activity related pain along with recurrent ankle sprains.

Exam

- Decreased subtalar motion (eversion and inversion) is noted on foot exam.

Imaging

- The standard AP and lateral radiographs of the foot can be helpful but may not always show an existing tarsal coalition.
- On the lateral radiograph, the “ant-eater sign” (long anterior process of the calcaneus) suggests the presence of a calcaneonavicular

coalition.

  - Additionally, on the lateral radiograph, the "C-sign of Lateur" (condensation underneath the medial facet of the calcaneus) suggests the presence of subtalar coalitions.
- The internal oblique foot radiograph can help identify calcaneonavicular coalitions.
- Talocalcaneal coalitions can be detected on a Harris view.
- CT scan/MRI of the foot can also be helpful in diagnosing coalitions.
  - They not only confirm the diagnosis but can detect additional coalitions in the symptomatic foot.

Treatment

- Initial treatment of a painful tarsal coalition is nonoperative.
- Treatment consists of a short leg walking cast/orthoses for 3 wks to provide symptomatic relief.
- Surgical treatment is considered after non-operative treatment failure.
  - The surgical treatment is usually excision of the coalition with interposition of fat graft.
  - For talocalcaneal coalitions, if greater than 50% of the middle facet is involved, fusion is considered a better option.

Accessory Navicular

Introduction

Approximately 10% of the general population have an accessory navicular. It is often bilateral and more common in girls than boys.

Presentation

- Patients present with pain and a palpable mass on the medial aspect of the foot just above the arch.
- It is usually discovered incidentally and is usually found in association with "overuse-syndromes" (e.g., posterior tibialis tendon traction apophysitis to the unstable navicular ossicle).

Treatment

- Treatment is usually geared toward managing the symptoms.
- Surgical excision is a last resort.

Forefoot Adductus

- Forefoot Adductus describes a spectrum of foot deformities that range from convexity of the lateral aspect of the foot to dynamic abduction of the great toe.
- The types of forefoot adductus include
  - metatarsus adductus
  - metatarsus varus
  - skewfoot
  - great toe abduction

Metatarsus Adductus

- This is a flexible forefoot deformity that is secondary to late intrauterine positional deformity.
- The forefoot is adducted (at tarsometatarsal joint) while the hindfoot maintains normal alignment.
- In these patients, it is important to check for hip dysplasia, as approximately 1% of metatarsus adductus cases have associated hip dysplasia.
- Metatarsus adductus resolves on its own.

Metatarsus Varus

- This is a rigid foot deformity due to early intrauterine positional deformity.
- The forefoot is rotated and fixed on the long axis of the foot, so that the sole faces the midline of the body.
- Unlike, metatarsus adductus, this deformity can persist without serial cast correction.

Skewfoot

- This complex deformity includes hindfoot plantar flexion, midfoot abduction, and forefoot adduction, with or without a tight heel cord.
- The spectrum of severity of this foot disorder ranges from idiopathic to those associated with neurologic disorders.
- Treatment consists of a combination of serial casting, heel cord lengthening and osteotomies.

Great Toe Abduction

- This is characterized by a dynamic deformity due to overactivity of the great toe abductor.
- This condition usually resolves on its own.

Cavus Foot

Introduction

Patients present with a high arch with or without clawing of the toes. It is important to check hands for clawing and/or wasting of the intrinsic muscles of the hand. The Coleman block is used to assess hindfoot flexibility. The cavus foot is usually associated with an underlying neurologic condition.

Treatment

- The approach to patients with a cavus foot is geared towards identifying the underlying neurological condition (static or progressive), if it is present.
- Afterwards, the foot deformity can be addressed, if needed.
- If surgery is warranted, the decision between soft tissue vs. bony procedure is based on flexibility of hindfoot deformity.

Bunions (Juvenile Hallux Valgus)

Introduction

This deformity is characterized by prominence of the head of the first metatarsal due to a combination of metatarsus primus varus (developmental deformity) and shoe wear. It usually presents in adolescence (especially in females).

Evaluation/Imaging

- The foot should be evaluated for the presence/absence of joint laxity, heel-cord contracture, and/or pes planus.
- The deformity should be quantified with standing AP and lateral foot x-rays, especially if considering surgical intervention.

Treatment

- Management starts with nonsurgical options (e.g., wearing shoes with a large toe box, night splints).
- Surgery is considered when nonsurgical options fail.
- Operative correction of the deformity is delayed until end of growth if possible as there is a high recurrence rate in juveniles.

Kohler Disease

Introduction

- Kohler disease is defined as avascular necrosis of the navicular.
- Patients are usually children aged 3–6 yrs old with complaints of a vague pain over the navicular bone.
- With the dorsomedial sided foot pain, localized swelling is noted as well.
- Radiographs show sclerosis with possible fragmentation and decreased size of the navicular bone.
- Kohler disease can be mistaken for infection.

Treatment

- This is a self-limiting disease and can be managed with immobilization in a short leg walking cast if symptomatic.
- Symptoms typically completely resolve in 7–15 mo.

Clubfoot

Introduction

Clubfoot, or talipes equinovarus, is a complex foot deformity that includes forefoot adductus in combination with hindfoot equinus and varus. Although the entire foot is supinated, the forefoot is pronated in relation to the hindfoot, resulting in cavus.

Etiology

- The etiology is multifactorial.
- The overall incidence is 1/1,000 live births and is bilateral 40% of the time.
- Clubfoot is usually idiopathic, but can also be associated with neuromuscular syndromes and chromosomal abnormalities.

Diagnosis

- Evaluation will reveal medial mid-foot crease and small heel.
- In the case of unilateral clubfoot deformity, the deformed foot is smaller and wider than the normal foot.
- The forefoot cannot be corrected to the abducted neutral position passively. In addition, the hindfoot cannot be brought down past the neutral position.
- On radiographs, the talus and the calcaneus are *parallel* on both AP and lateral views.

Natural History

- Untreated clubfoot deformity results in progressive disability in walking.

Treatment

- If started early, serial casting can be very successful.
- The Ponseti Technique of casting followed by heel cord tenotomy can effectively treat club foot deformity.
- The sequence of correction: “CAVE” = Cavus, Adductus, Varus, Equinus.

- Surgical release of clubfoot deformity is reserved for resistant or refractory clubfeet.
  - If surgical treatment is undertaken, an "a la carte" approach is recommended as opposed to a complete posteromedial release.
- It should be noted that clubfoot secondary to neuromuscular disorder can be more difficult to treat in comparison to idiopathic clubfoot.

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SCOLIOSIS, KYPHOSIS, SPONDYLOLYSIS/SPONDYLOLIST

LINDSAY ANDRAS

Scoliosis

Introduction

- Scoliosis is defined as curvature of the spine of more than 10 degrees.
- It can be
  - idiopathic
  - congenital
  - neuromuscular
  - or associated with trauma, tumor, neurofibromatosis, Marfan, Ehlers Danlos, muscular dystrophy or other syndromes
  - Idiopathic scoliosis is a diagnosis of exclusion.

Risk of Progression

- Progression depends on
  - the etiology of the curve
  - genetic predisposition
  - curve magnitude
  - amount of growth remaining
- The Risser sign (amount of ossification in iliac apophysis, is one indicator of growth remaining (Fig. 9.3).
  - If untreated, 68% of patients who are Risser 0–1 with a 20–29

degree curve will progress

  - while only 23% of patients who are Risser 2–4 with a curve of the same magnitude will show signs of progression.

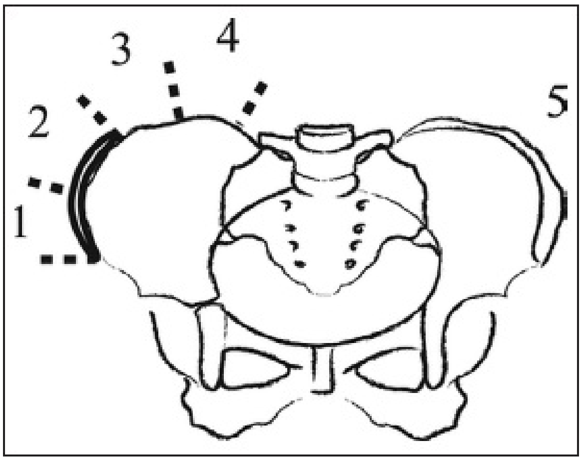

Figure 9.3 Risser sign. The iliac apophysis ossifies in a predictable manner beginning laterally and progressing medially. The capping of the iliac wing is correlated with slowing and completion of spinal growth, generally occurring over a period of 18–24 mo. (From Weinstein SL; Flynn JM, Lovell and Winter's Pediatric Orthopaedics Wolters Kluwer; Philadelphia, PA. 2013 with permission).

Clinical History

- Family history is often positive, with up to 11% of first-degree relatives affected.
- Approximately 23% of patients with idiopathic scoliosis present with back pain.
- Further work-up is indicated if
  - the pain is localized, constant, progressively worsening
  - or associated with symptoms of weakness, abnormal gait or episodes of bowel/bladder incontinence.
- Assess amount of growth remaining: age of menarche, parental height. Ask how and when curve was first appreciated and if progression has been observed since that time.

Physical Exam

- Check whether shoulders and pelvis are level and for the presence of any truncal shift.

- Adams forward bend test, using a scoliometer, is done to assess rotation.
- Rib prominence should be on the same side as the curve convexity.
  - If the prominence is on the same side as the curve concavity, it is usually related to leg length discrepancy and not a structural curve.
- A scoliometer reading of 5 degrees is considered abnormal and correlates to an approximately 20 degree curve, which is an indication to order radiographs.
  - The scoliometer is helpful for monitoring mild curves without obtaining numerous radiographs.
  - The following findings suggest that the curve is not idiopathic:
    - gait abnormality (check ability to walk on heels and hop on each foot independently)
    - kyphosis
    - foot deformity (especially if unilateral)
    - popliteal angle more than 50 degrees, unequal reflexes (especially abdominal), sustained clonus
    - decreased sensation or strength.

Imaging

- If possible, x-rays should be obtained standing (noting that the air bubble in the stomach is flat on the bottom confirms this).
  - Always check lateral x-rays for presence of spondylolisthesis (may affect surgical planning).

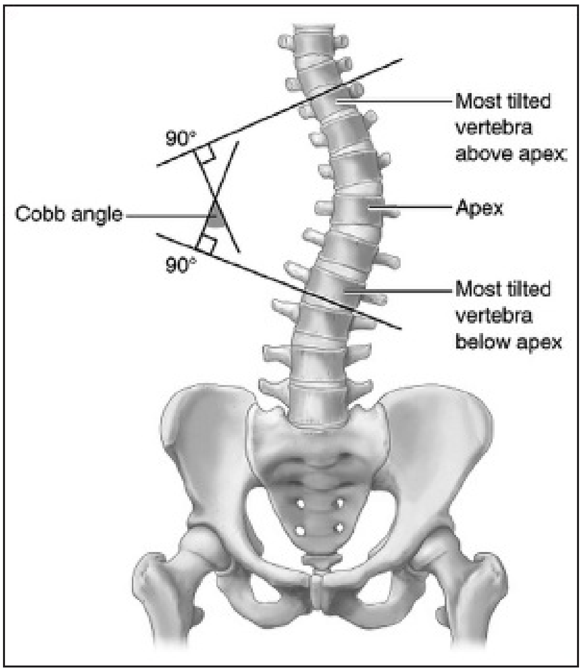

Figure 9.4 Cobb Angle. Cobb angle is a quantitative measure of the coronal curvature. Lines parallel to the vertebral endplates of the end vertebrae are drawn. Perpendiculars to these two lines are drawn. The angle subtended is the Cobb angle. (From Flynn JM, Operative Techniques in Pediatric Orthopaedics Orthopaedics Wolters Kluwer; Philadelphia, PA. 2010 with permission).

- Hypokyphosis of the thoracic spine is expected.
  - Identify apex of curve(s) and note level.
  - Identify the superior and inferior vertebrae of each curve (the most tilted vertebral endplates).
- Measure Cobb angle
  - This is the angle between a line along the superior endplate of the most angled vertebrae above the apex of the curve and a line along the inferior endplate of the most angled vertebrae below the apex of the curve, (Fig. 9.4).
  - Cobb measurement has an average of
    - 5-degree intraobserver variability and
    - 7 degrees of interobserver variability.
  - When determining fusion levels, count to check that there are 12 thoracic and 5 lumbar vertebrae and draw central sacral vertebral line (CSVL), which is a line perpendicular to the iliac wings and a

line bisecting L5.

- Note Risser sign (ossification of iliac apophysis).
- Assess for fusion of iliac apophysis and whether the triradiate cartilage is closed or still open.
- Indications for MRI:
  1. neurologic abnormality (weakness/abnormal reflexes)
  2. severe pain
  3. young patients (less than 11 yrs old) with curves greater than 20 degrees
  4. atypical patterns (Left sided thoracic curve, congenital scoliosis, short angular curves or severe deformity/greater than 70 degrees)
  5. rapid progression (more than 1 degree/mo)

Treatment

- **Bracing:** Controversial.
  - It is only indicated for curves 20 to 45 degrees and in patients with substantial growth remaining (Risser 3 or less).
  - The apex of curve should be at T7 or below for a Boston type brace (TLSO).
  - If the apex is above T7, a Boston brace is ineffective and a CTLSO is required.
  - Obtain an x-ray in the brace to assess curve correction: at least 25% curve correction in the brace is desired.
  - At best, bracing prevents progression.
  - After completion of treatment, a rebound effect is often observed.
- **Surgical:**
  - Indicated for curves over 50 degrees (some say more than 45 degrees with significant growth remaining).
  - Posterior spinal fusion (PSF) is the most common surgery performed.

- Anterior spinal fusion (ASF) may be indicated for single curves: it allows for a shorter fusion and thus preservation of additional motion segments.
- Historically, ASF + PSF is recommended for very young patients to prevent crankshaft, but this has been challenged when using pedicle screw constructs.

- Level selection in PSF: if curves are compensatory and not structural (less than 25 degrees with bending) then a selective fusion of the main structural curve alone can be performed.
  - Include all levels from which the Cobb angle is measured.
  - Do not stop at any level of kyphosis (usually T6–T8).
  - CSVL should travel through the vertebral body at the distal end of the surgical construct; do NOT stop at the apex of the compensatory curve.
  - If left shoulder is high on exam or if the left clavicle is high on x-ray, include the upper thoracic curve as well (fuse to T2).
- Complications include:
  - ileus (6%)
  - early infection (1–2%)
  - late infection (up to 5%)
  - pseudarthrosis (3%)
  - neurologic deficit (0.4–0.7%).
- If there is a change in neuromonitoring:
  1. check to see if anesthesia has changed inhalational agents
  2. have neuromonitoring personnel verify electrode position
  3. release correction
  4. increase blood pressure to a mean of at least 80 mm Hg
  5. transfuse if the hematocrit is low
  6. verify that no instrumentation has migrated into the canal
  7. remove instrumentation
  8. consider giving steroids and lidocaine (controversial)

Kyphosis

Introduction

- Kyphosis is defined as an abnormal increase in the sagittal plane forward curvature (hunchback).
- May be congenital, postural or Scheuermann.
  - Congenital types include
    - failure of segmentation
    - failure of formation
    - rotary subluxation
  - Postural kyphosis typically has a smooth round curve on Adam forward bending as opposed to the sharp angulation seen with Scheuermann.

Clinical History

- Same questions are relevant as described in scoliosis section (see previous).
- Scheuermann kyphosis also has a genetic predisposition and is more common in males.

Physical Exam

- A thorough neurologic exam should be performed.
- See previous description in scoliosis section.

Imaging

- Normal sagittal alignment:
  - T2–T10 with Cobb angle of 20–40 degrees
  - T10–L2 is straight
  - L2-sacrum has lordosis that is greater in magnitude than the thoracic kyphosis.
- Greater than 45 degrees of thoracic kyphosis is considered abnormal.
- The Sorensen criterion for diagnosis of Scheuermann kyphosis requires more than 5 degrees of wedging at 3 adjacent vertebrae.

- Other classic radiographic findings include:
  - endplate irregularities,
  - Schmorl nodes
  - loss of disk space height.
  - Be sure to obtain full length films, as there is a 50% incidence of spondylolysis in patients with Scheuermann kyphosis.

Treatment

- Brace treatment is controversial.
  - Most studies have been done using a Milwaukee brace (CTLSO), which has a high rate of noncompliance.
  - A modified Boston brace is more commonly used.
  - There is limited evidence, but patients that have more than 1 year of growth remaining and with curves more than 75 degrees are thought to be good prognostic indicators for successful brace treatment.
  - Treatment requires a minimum of 18 mo.
- Surgical treatment is indicated for
  - curves more than 75 degrees,
  - associated neurologic conditions,
  - significant pain
  - failure of brace treatment.
- Obtain a lateral x-ray with the patient lying supine over a sandbag to assess curve flexibility.
  - Curves that are still more than 50 degrees over a sandbag may need an anterior release in conjunction with PSF (controversial).
  - Check hamstrings preoperatively as popliteal angles more than 30 degrees are associated with greater risk of postoperative imbalance.
  - Do NOT instrument at the curve apex.
  - The distal end of the fusion should include the sagittal stable vertebra ([SSV]-the most proximal lumbar vertebral body

touched by the vertical line drawn from the posterior-superior corner of the sacrum on the lateral x-ray).

- Complications include:
  - neurologic injury
  - junctional kyphosis (20–30%)
  - overcorrection
  - infection

Spondylolysis/Spondylolisthesis

Introduction

- Spondylolysis is a stress fracture of the pars interarticularis.
- It occurs in 6% of the general population and 53% of the Eskimo population.
- Spondylolisthesis is forward slippage of one vertebrae on another and can be
  - traumatic
  - pathologic
  - isthmic (related to pars defect)
  - dysplastic (congenital deficiency of facet joint)
  - degenerative
- Isthmic and dysplastic are the most common types in children.

Clinical History

- Same as previous sections, but also ask about any activities that cause repetitive hyperextension and duration and severity of any associated pain.

Physical Exam

- Complete neurologic exam.
- Spondylolysis: if pain is present, it usually localizes to the lumbosacral area and increases with hyperextension.

- Spondylolisthesis: patients have hyperlordosis.

Imaging

- AP, lateral, and oblique plain radiographs.
- For spondylolysis, look for a defect in the pars interarticularis (Scotty dog sign).
- If not detected, proceed with bone scan or CT.
- MRI is controversial.
- Spondylolisthesis is defined by the degree of forward translation:
  - grade 1: 0–25%;
  - grade 2: 25–50%,
  - grade 3: 50–75%,
  - grade 4:75–100%.
- Slip angle measures the sagittal rotation of L5 and is measured by the angle between lines drawn perpendicular to the posterior edge of L5 and S1.
- There is a higher risk of progression with increased pelvic incidence.
- Pelvic incidence is defined as the angle between a line perpendicular to the sacral endplate at its midpoint and a line connecting the same point to the center of the femoral head (mean for children is 47 degrees and for normal adults is 57 degrees).

Treatment

- Observe patients with asymptomatic spondylolysis.
- Those with symptomatic spondylolysis are initially treated with activity modification and a brace.
- If brace treatment fails, proceed to a one level PSF or pars repair.
  - Prior to doing a pars repair, an MRI is required to check the viability of the vertebral disks (a degenerative disk is better treated with a fusion).
  - Asymptomatic low grade spondylolisthesis is followed with serial x-rays.

- Symptomatic low grade (1 and 2) slips are treated with activity modification +/− bracing.
- If conservative treatment fails, perform in situ PSF.
- High grade slips require L4–S1 PSF with possible decompression (Gill procedure).
- Reduction of high grade slips at the time of fusion is associated with increased iatrogenic nerve injury.
- Neurologic injury may develop intraoperatively or postoperatively.
- Cauda equina has even been described in patients with no preoperative neurologic issues who have undergone in situ fusions.
- The femoral nerve is at risk of traction injury and some surgeons prefer to keep hips flexed for 2 d postoperatively.

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SKELETAL DYSPLASIAS

ARISTIDES I. CRUZ, JR

Skeletal Dysplasias

Introduction

- Skeletal dysplasias encompass a number of diseases that are characterized by disorders of growth and remodeling of bone and its cartilaginous precursor.

Terminology

- The term "dwarfing condition" refers to disproportionately short stature
  - It is further referred to as **short trunk** and/or **short limb** dwarfism when describing clinical syndromes.
- Short limb dwarfism can be subdivided into types:
  - *Rhizomelic:* shortening of the proximal portion of the limb.
  - *Mesomelic:* shortening of the middle portion of the limb.
  - *Acromelic:* shortening of the distal portion of the limb.

Normal Growth

- Long bone growth occurs via *endochondral ossification* in which bone is formed from a cartilaginous precursor.
- Flat bone (i.e., skull) growth occurs via *intramembranous ossification* in which there is no cartilage precursor.
- The growth plate consists of several zones, each of which may be involved in different disease processes:
  - reserve zone

- proliferative zone
- hypertrophic zone
- zone of provisional calcification

ACHONDROPLASIA

Etiology

- Achondroplasia is the most common skeletal dysplasia with an incidence of 1/30,000 to 1/50,000.
- It is caused by a mutation in ***FGFR3*** (fibroblast growth factor-3).
- It is inherited as an **autosomal dominant** trait but most cases are due to a spontaneous mutation.
- The underlying pathologic process **limits endochondral bone formation in the zone of proliferation** of the physis.

Clinical Features

- The bones with the highest rate of growth (i.e., distal femur/proximal humerus) are most affected resulting in *rhizomelic* dwarfism.
- Bones formed via endochondral ossification (long bones, facial bones) are affected (cranial bones unaffected).
  - Clinical manifestations:
    - normal size trunk
    - frontal bossing
    - midface hypoplasia
    - thoracolumbar kyphosis
    - "trident" hands
    - "champagne glass" pelvic outlet
    - lumbar spinal stenosis with lordosis and short pedicles
    - genu varum
    - posterior head subluxation/dislocation

- **Foramen magnum stenosis** may cause central sleep apnea and weakness in early life.
- NOT associated with cervical instability.

Treatment

- The most common orthopaedic problems include genu varum, lumbar spinal stenosis, and thoracolumbar kyphosis.
  - Genu varum
    - Bracing is ineffective; treat with **corrective osteotomy** with internal or external fixation.
    - Tibial torsion should also be corrected if it is >10–20 degrees.
  - Lumbar spinal stenosis
    - Most patients will present with **neurogenic claudication,** although some patients will present with muscle weakness alone.
    - Symptomatic stenosis usually develops during the third decade of life.
    - The clinical diagnosis of spinal stenosis is an immediate indication for surgical decompression.
  - Thoracolumbar kyphosis
    - This is present in most infants presumably because of
      - low muscle tone
      - ligamentous laxity
      - relatively large cranium
    - The kyphosis is typically centered over the twelfth thoracic or first lumbar vertebra.
      - Most will **improve by age 2–3** once strength increases and walking begins.
      - Prevent by avoiding unsupported sitting during early life.
    - Extension bracing is indicated if
      - it is accompanied by anterior vertebral wedging,

- does not reduce below 30 degrees on prone hyperextension radiographs,
- does not resolve by age 3 yrs.

Pseudoachondroplasia

Etiology

- Pseudoachondroplasia is due to a mutation in *cartilage oligometric protein (COMP)* located on chromosome 19.
- Inherited as an *autosomal dominant* trait.

Clinical Features

- Characterized by *rhizomelic* limb shortening.
- There is *normal growth until age 2* years and patients are often not recognized as having a skeletal dysplasia at birth.
- Patients have *normal facial features.*

Imaging

- Epiphyses: ossify late and have irregular appearance.
- Metaphysis: broad, irregular at ends, and flared at edges.
- Ligamentous laxity results in excessive knee valgus or "windswept" knees (one varus, one valgus).
- **Cervical instability:** almost 50% of patients have odontoid hypoplasia or aplasia; evaluate with flexion/extension C-spine radiographs at regular intervals.
- There is **platyspondyly** without increased incidence of spinal stenosis.

Treatment

- Cervical instability (ADI $>$ 8 mm, myelopathy/neurologic changes) is treated with posterior cervical fusion.
- Valgus or varus knee deformity often requires correction.
- The choice of surgical procedure is surgeon dependent and is

associated with a high recurrence rate.

- These patients have an increased risk of early onset osteoarthritis.

Diastrophic Dysplasia

Etiology

- Diastrophic dysplasia is due to a defect in the **sulfate transport protein** located on chromosome 5.
- Its inheritance pattern is **autosomal recessive**.
- It is a relatively rare condition except in Finland where 1–2% of the population are carriers.

Clinical Features

- *Rhizomelic* dwarfism is apparent from birth.
  - 50% of patients are born with a *cleft palate.*
  - Pathognomonic features:
    - *Cauliflower ears* (80–85% of cases)
    - *Hitchhiker thumb* (95% of cases).
- *Cervical spine:*
  - bifid posterior arches of the lower cervical vertebrae.
  - Cervical kyphosis is present in ⅓ of patients.
  - The clinical course of the kyphosis is variable with spontaneous resolution in many cases.
- *Scoliosis:*
  - develops in >⅓ of patients.
  - Curves often do not progress >50 degrees.
- *Extremities:*
  - persistent hip flexion contractures (may lead to compensatory increased lumbar lordosis).
  - Knee flexion contracture and genu valgum are present.

- **Lateral patellar subluxation** is present in 25% of patients.
- These patients also get early onset **hip and knee osteoarthritis.**
- **Rigid clubfoot or skewfoot** is common.

Treatment

- *Cervical spine:* periodic monitoring of kyphosis.
  - The behavior of the kyphosis is related to the severity of the diastrophic dysplasia.
  - **Observation** is indicated if the kyphosis is non-progressive and there is no evidence of neurologic compromise.
  - **Bracing** is indicated if the deformity is progressive without evidence of neurologic compromise.
  - *Posterior cervical fusion* is indicated if the kyphosis continues to progress despite bracing OR if there are neurologic changes.
- *Hips:* consider soft tissue release if flexion contracture >40 degrees and there is no evidence of proximal femoral epiphyseal flattening.
  - *Hip dysplasia* is often progressive and treatment must be individualized (femoral vs. pelvic/acetabular osteotomy vs. nonop management).
  - *Special considerations for total hip arthroplasty* (THA):
    - small or custom implants, consider femoral shortening osteotomy,
    - there is increased anterior femoral bowing, consider contracture release (adductor, rectus femoris, sartorius),
    - possible increased incidence of femoral nerve palsy.
- *Knees:* complete correction of flexion contractures are often prohibited by the shape of the distal femoral condyles.
  - Consider *distal femoral extension osteotomy* at skeletal maturity for residual contracture.
  - *Patellar relocation* procedure may improve extension power.
  - *Special considerations for total knee arthroplasty:*
    - extensive lateral release/patellar relocation

        - use constrained implants
        - use short or bent stems
- *Feet:* foot deformities are **rigid** making casting futile.
    - Goal of treatment is to achieve a plantigrade foot.
    - Surgery should be delayed until at least 1 yr old (feet are big enough to work on) and must ensure cervical stability pre-op.
    - Extensive releases should be performed to fully correct the deformity.
    - Partial **recurrence is common**.
    - Salvage procedures include talectomy, talocalcaneal decancellation, and arthrodesis.

Cleidocranial Dysplasia

Etiology

- Cleidocranial dysplasia primarily affects bones of intramembranous ossification (i.e., clavicle, cranial bones).
- It is associated with a defect in the ***RUNX2/CBFA*-1** gene on chromosome 6, which encodes a transcription factor for osteocalcin.

Clinical History

- The most pathognomonic clinical manifestation is the absence (or partial absence) of the clavicles and a widened cranium.
- The clavicles are completely absent in 10% of cases.
- Patients have mild to moderate short stature.
- The classic diagnostic feature is that patients are able to *approximate their shoulders together* due to the absence of the clavicles.
- Patients also have a *widened pubic symphysis* and *coxa vara.*

Treatment

- There is no need for treatment of the absent or partially formed clavicles.

- Coxa vara may be treated with valgus producing intertrochanteric osteotomy if the neck-shaft angle is <100 degrees and the patient has a Trendelenberg gait.

Multiple Epiphyseal Dysplasia

Etiology

- Multiple epiphyseal dysplasia (MED) involves multiple epiphyses WITHOUT spinal involvement. It mostly affects the load bearing joints.
- It has an *autosomal dominant* pattern of inheritance.
- Multiple genes have been identified to be involved:
  - *COMP*
  - *COL9 A* (which encodes for Type IX collagen whose function is to link Type II collagen fibrils).

Clinical History

- MED typically presents in late childhood.
- Symptoms include
  - joint pain
  - gait disturbances
  - decreased range of motion of the joints
  - angular deformities of the knees
- Patients have somewhat short stature.
- There is no spine or visceral involvement.
- The prognosis for patients' disability depends on the extent of epiphyseal involvement and ranges from mild joint problems to severe osteoarthritis.

Imaging

- Multiple epiphyses are involved with minimal metaphyseal involvement.

- The epiphyses are small and fragmented.
- There is knee valgus with "double layered" patellae on lateral radiographs.

- *Distinguish MED from Legg-Calvé-Perthes disease:*
  - there are *synchronous* and *symmetric* changes of the proximal femoral epiphyses in MED
  - bilateral Perthes disease will present in different states of fragmentation.
- The acetabular abnormalities are more pronounced in patients with MED.
- Obtain radiographs of other joints when suspecting patients with MED.

Treatment

- Progressive genu valgum may be treated with temporary hemiepiphysiodesis or osteotomy.
- The goal on treating hip subluxation is *to maintain acetabular coverage.*
- In order to achieve this, acetabular procedures are primarily used (i.e. Shelf augmentation).
- Patients often have pre-existing coxa vara, which precludes femoral osteotomy.
- Degenerative joint disease is treated with
  - NSAIDs
  - physical therapy
  - total joint arthroplasty (for end stage disease)

Spondyloepiphyseal Dysplasia

Etiology

- There are two types of spondyloepiphyseal dysplasia (SED), each type distinguished by the age of onset and severity.

- *SED congenita:* this is the more severe form.
  - The disease is apparent from birth and is inherited as an *autosomal dominant* trait, although most patients acquire the disease due to a new mutation.
  - ***COL2A*1** encodes Type II collagen and affects the *proliferative zone* of the physis.
- *SED tarda:* patients have less severe involvement.
  - The disease presents in late childhood or early adulthood.
  - It is inherited as an *X-linked dominant* trait; therefore, males are more commonly and more severely involved than females.
  - It is associated with the SEDL gene, which has an unknown function.

Clinical/Radiographic Features

- Both forms of SED are associated with *cervical instability* with *os odontoideum* or odontoid hypoplasia.
- Spine radiographs display *platyspondyly* in both types and there is delayed epiphyseal ossification in both types.
- *SED congenita:* associated with
  - coxa vara
  - genu valgum
  - pes planovalgus
  - retinal detachment
  - myopia
  - hearing loss
- SED tarda:
  - must screen for atlantoaxial instability
  - there is no lower limb bowing
  - there is occasional hip subluxation.

Treatment

- *Cervical instability*

- Frequent radiographic evaluation with flexion-extension radiographs is necessary.
- Surgical stabilization is indicated if there is evidence of instability or if there is neurologic compromise.

- *Scoliosis*
  - Bracing may be used if curves are <40 degrees; however, there is no evidence proving the long-term efficacy of bracing.
  - *Posterior spinal fusion* with instrumentation is indicated for progressive curves.
  - *Anterior spinal fusion* is indicated in young patients (<11 yrs) or if patients have stiff curves (as evaluated on bending radiographs).
- *Hip subluxation*
  - Proximal femoral osteotomy is indicated if the neck-shaft angle is <100 degrees.
  - Pelvic and femoral osteotomies may be needed to maintain femoral head coverage.
  - It is important to evaluate and potentially correct knee alignment abnormalities as this may have effects at the hip.
  - THA is often necessary.
    - THA is often difficult due to stiffness
    - the need for custom implants
    - the need for concurrent osteotomy.

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BONE MINERAL DISORDERS

CORINNA C. FRANKLIN

Normal Skeletal Growth & Composition

- Bone Growth:
  - *Long* bones grow by endochondral ossification, in which bone forms over a cartilage template.
  - *Flat* bones grow by intramembranous ossification, in which fibrous connective tissue is converted into bone.
- Bone formation and remodeling involves coupling between osteoblasts and osteoclasts.
  - Osteoblasts form bone matrix and lay down bone during growth and remodeling.
  - On the other hand, osteoclasts break down, or reabsorb bone.
  - The rate at which osteoclasts break down bone is regulated by osteoblast activity.
    - Osteocytes are former osteoblasts that become embedded in bone matrix and regulate homeostasis.
    - The extracellular matrix of bone is
      - 60–70% mineral matrix, which is largely hydroxyapatite and tricalcium phosphate,
      - 20–25% organic matrix, which is mostly Type I collagen.
- Childhood and adolescence are the critical times to achieve peak bone mass.
  - Calcium requirement for calcium:
    - 4–8 yrs old: 800 mg/d of calcium

- 9 through 18 years old: 1,200 mg/d.

Mineral Metabolism

- Calcium is essential for bone health and mineralization, and is also essential for proper muscle and nerve function.
- In general, bones are a repository for calcium, which is absorbed in the GI tract and excreted by the kidneys.
- Prolonged calcium deficiency will result in bone loss due to the mobilization of calcium from bone, so that it can be used for other more essential body functions.
- Parathyroid hormone (PTH) regulates the production of active vitamin D based on serum calcium levels (a low calcium level leads to higher production of PTH by the parathyroid glands).
  - PTH functions with vitamin D to increase calcium resorption in the gut.
  - PTH also mobilizes calcium from bones and decreases renal phosphate resorption.
- The active form of vitamin D is 1, 25-dihydroxyvitamin D.
  - Vitamin D sources include
  - diet,
  - supplements
  - exposure to sunlight (D2 and D3).
  - This form of vitamin D must be converted to 25-hydroxyvitamin D in the liver, and then converted to 1, 25-dihydroxyvitamin D by the kidneys.
- Vitamin D regulates calcium homeostasis.
  - It increases intestinal absorption of calcium and phosphate along with increasing calcium resorption by the kidney.
- Other factors affecting bone mass include
  - hormones such as estrogen, the lack of which can lead to decreased bone density, and mechanical stress;

- bone remodels in response to stress (Wolff law) such that immobilization or lack of weight bearing can lead to bone loss.

Osteogenesis Imperfecta

- Osteogenesis Imperfecta (OI) is characterized by abnormal, weak bone that predisposes the patient to skeletal fragility.
- OI comprises a spectrum of diseases that are generally related to disordered collagen production, either in quantity or quality.
  - Most types are caused by a defect in type I collagen, specifically involving genes *COL1A1* and *COL1A2*.
  - Patients may have
    - multiple fractures (olecranon apophyseal fractures are characteristic)
    - scoliosis
    - basilar invagination
    - and joint laxity
    - as well as blue sclerae (not present in all forms) and problems with teeth and hearing.
- Sillence originally described four types of OI.
  - Type I is mild:
    - is characterized by insufficient normal collagen
    - with multiple fractures but without limb deformities
    - and presenile deafness.
  - Type II is the most severe and usually leads to perinatal death.
  - Type III is severe but survivable, with patients who are short and have severe limb deformities and bowing, as well as biconcave vertebrae.
  - Type IV is moderate
  - is characterized by patients who are short statured with bowed limbs and multiple fractures.

  - In addition to these four, more types are being added/discovered as genetic and phenotypic understanding grows.

Treatment

- Bone fragility may be treated with bisphosphonates.
- Severe bowing of limbs or recurrent fractures are usually treated with intramedullary fixation (expandable options are available for growing children).
- Patients presenting with multiple or repeat fractures should be screened for child abuse before OI is assumed.

Rickets

Introduction

- Rickets is defined as defective bone mineralization and inadequate calcification of the growing cartilage matrix.
- It is related to altered calcium/phosphate homeostasis.
- This disorder leads to deformity and growth impairment, which is manifested as
  - bowing of the limbs
  - physeal widening
  - osteopenia
  - fractures

Imaging

- The classic radiographic finding is widened and indistinct growth plates with a cupped metaphysis.
- The chest may have a "rachitic rosary" appearance—enlargement of the costochondral junction.

Diagnosis

- Basic workup includes
  - serum calcium

- phosphate
- vitamin D
- alkaline phosphatase levels.

Classification

- Specific types of rickets:
- **Hypophosphatemic**
  - This is an x-linked dominant disorder and the most common subtype of rickets in North America.
  - It is caused by a defect in the *PHEX* gene, and due to inadequate renal reabsorption of phosphate.
  - Labs show low phosphate and high alkaline phosphatase levels.
  - Presentation includes rickets and short stature.
  - Treatment is with active vitamin D and requires careful metabolic monitoring.
- **Vitamin D-deficient**
  - This form is purely a nutritional disorder.
  - Lab values reveal
    - low vitamin D, calcium, and phosphate levels,
    - with high PTH and alkaline phosphatase levels.
  - This condition is treated with vitamin D supplementation.
- **Vitamin D-dependent**
  - This is broken down into two types: Type 1 and Type 2
  - **Type 1** results from a defect in renal conversion of the inactive to the active form of vitamin D.
    - Labs show
      - low calcium and phosphate levels
      - high PTH and alkaline phosphatase levels
      - and a significantly decreased 1,25-dihydroxyvitamin D level.
    - This condition is treated with active vitamin D replacement.

- **Type 2** results from a defect in the receptor for active vitamin D.
  - Labs show
    - low calcium and phosphate levels
    - high PTH and alkaline phosphatase levels
    - and significantly increased 1,25-dihydroxyvitamin D levels.
  - This condition is treated with high doses of vitamin D and calcium.
- **Hypophosphatasia**
  - This is an autosomal recessive disorder that results in alkaline phosphatase deficiency.
  - Labs show
    - high calcium and phosphate levels
    - and low alkaline phosphatase levels.
  - Presentation includes pathologic fractures and abnormal dentition.
  - No clear medical treatment has yet been described.
- **Renal osteodystrophy**
  - End-stage renal disease leads to inadequate clearance of phosphate, ultimately leading to hypocalcemia and hyperparathyroidism.
  - Features of hyperparathyroidism include
    - subperiosteal erosions at the lateral distal radius
    - ulna and medial proximal tibia.
  - Dysfunctional kidneys also fail to produce adequate vitamin D, leading to rickets.
  - Treatment includes
    - dietary phosphate restriction
    - phosphate binding agents
    - vitamin D supplementation
    - and ultimately, renal transplantation.

Osteopetrosis

- Osteopetrosis is a sclerosing bony dysplasia, in which inadequate osteoclastic resorption leads to dense bone that is brittle and prone to fracture.
- Clinically, it may present with
  - fractures
  - anemia (as the medullary canal disappears hematopoiesis is diminished)
  - hearing loss
  - or complications with tooth extraction
- Radiographs demonstrate thick, dense bone with widened metaphyses.
- Definitive treatment is with bone marrow transplantation.

Scurvy

- Vitamin C deficiency leads to a decrease in collagen synthesis, particularly at the metaphysis.
- Clinical features include
  - microfractures
  - metaphyseal collapse
  - and hemorrhage
- Radiographs demonstrate metaphyseal osteopenia and a dense white band (representing the zone of provisional calcification).
- Treatment is with vitamin C replacement/supplementation.

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NEUROMUSCULAR DISORDERS

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Cerebral Palsy

Introduction

- Cerebral palsy (CP) is a general term that describes a range of clinical syndromes that lead to impaired motor function.
  - This impairment is due to a physiologic insult to the developing the brain, the manifestations of which results in a disorder of posture and movement.
- By definition, CP is a **static encephalopathy**.
  - However, the resultant affect on motor function is often progressive due to muscle spasticity and weakness as the patient grows.
  - This results in joint contractures, gait abnormalities, and other orthopaedic problems.
  - In addition to the motor manifestations, CP can also result in speech, sensory, and cognitive difficulties.
- The incidence is approximately 1–7/1,000 live births.
- Prematurity increases this risk.

Classification

- CP can be described based on physiologic, anatomic, and functional classifications.
- *Physiologic:*
  - *Spastic type:*
    - results in increased muscle tone or rigidity especially with rapid stretch.

    - This leads to joint contractures and gait abnormalities in which many orthopaedic interventions are useful.
  - *Athetoid type:*
    - results in writhing, involuntary movements and dystonia;
    - results of orthopaedic interventions are unpredictable.
  - *Ataxic type* (cerebellar lesion) CP
    - is rare
    - and results in difficulty with coordinated movement, especially walking.
  - *Mixed type:*
    - results in a combination of pyramidal and extrapyramidal type symptoms with variable amounts of spasticity and athetosis.
  - Anatomic:
    - *Quadriplegia*—all four limbs affected; children most adversely affected.
    - *Diplegia*—both lower extremities are involved to a greater extend than the upper extremities.
    - *Hemiplegia*—one side of the body is more severely affected.
  - Functional:
    - Based on Gross Motor Functional Classification System (GMFCS) (Fig. 9.7).

Nonoperative Management

- Physical therapy (PT) and occupational therapy (OT) are mainstays of nonoperative treatment.
  - The goal of PT is to
    - prevent joint contractures through stretching, bracing, splinting, serial casting and standing programs
    - improve patients' gait and functional mobility.
  - OT addresses fine motor function and activities of daily living (self-feeding, self-hygiene, etc.).

- Anti-spasticity agents
  - Baclofen—may be administered orally but side effects (excessive sedation) often poorly tolerated.
  - Intrathecal baclofen—administered through intrathecal pump and is associated with less sedation.
- Botulinum Toxin A—
  - affects neuromuscular junction by irreversibly binding proteins on presynaptic membrane necessary for acetylcholine release.
  - Botox is used in dynamic (i.e., nonfixed) contractures and often in conjunction with a serial casting program, bracing and PT.
  - Can also be used to delay surgery.

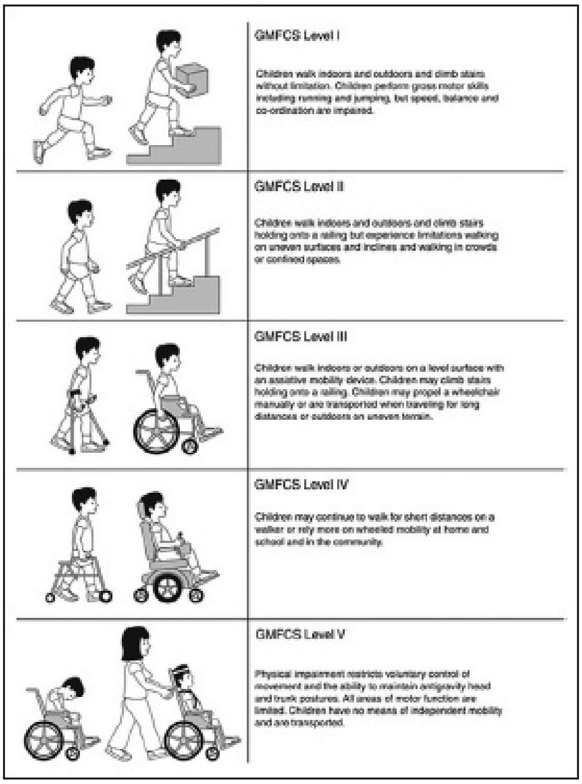

Figure 9.7 Gross Motor Functional Classification System (GMFCS). (Used with permission from Palisano RJ, Rosenbaum P, Walter S, Russell D, Wood E, Galuppi B: Development and reliability of a system to classify gross motor function in children with cerebral palsy. *Dev Med Child Neurol.* 1997;45:113–120. Illustrated by Kerr Graham and Bill Reid, The Royal Children's Hospital, Melbourne).

Surgical Technique

- Selective dorsal rhizotomy
  - neurosurgical procedure that reduces spasticity by selectively cutting rootlets of L1–S1.
- Ideal candidate:
  - ambulatory
  - diplegic
  - 3–8 yrs old
  - good selective motor control
  - no fixed contractures
  - pure spasticity (i.e., no extrapyramidal or cerebellar symptoms)
  - and "normal" intelligence

Specific Problems and Treatment

- Spine
  - *Scoliosis* is associated with the severity of CP involvement; those with quadriplegia are most severely affected.
  - Scoliosis in quadriplegia differs from idiopathic scoliosis:
    - occurs earlier in life
    - less responsive to bracing
    - more likely to progress even after skeletal maturity (especially if the curve is >40 degrees).
  - Bracing may be beneficial to improve sitting balance but is unlikely to prevent progression.
  - *Surgery* (posterior spinal fusion with instrumentation) is indicated once the curve exceeds 40–45 degrees.
    - Surgical correction and fusion in severely involved patients may be controversial for several reasons:
      - the significant morbidity of surgery
      - minimal improvement of physical function
      - and post-op complications.
  - Most parents and orthopaedic surgeons, however, still consider

surgery worthwhile because of improved sitting balance, which improves quality of life and facilitates parent/caregiver care.

- *Surgical considerations:*
  - pre-op hyper-alimentation (most patients are malnourished) may require a surgically placed feeding tube;
  - monitor intra-op blood loss and replace accordingly;
  - post-op pulmonary problems should be prevented by respiratory therapy and rapid mobilization;
  - long surgical constructs from upper thoracic spine to pelvis (if pelvic obliquity >10 degrees and nonambulatory);
  - liberal use of allograft bone to promote fusion.

- Hip
  - Hip subluxation and progression to dislocation are common problems because of
    - muscle imbalance and spasticity (adductors and iliopsoas)
    - pelvic obliquity
    - acetabular dysplasia
    - excess femoral anteversion
    - increased femoral neck valgus
    - lack of weight bearing
    - and abnormal resultant force vectors about the hip
  - Hip subluxation will develop in 50% of patients.
    - Dislocation can cause
      - pain,
      - associated contractures,
      - pressure ulcers,
      - sitting imbalance,
      - and difficulty with care and hygiene.
  - Treatment
    - Prevention is KEY.

    - Screening AP pelvis is recommended starting at age 18 mo in those with bilateral involvement.
    - Radiographs should be repeated every 6–12 mo.
    - Quantify hip subluxation using Reimer's migration index (Fig. 9.8).
  - Nonsurgical treatment may consist of
    - PT to stretch tight adductors and hip flexors
    - and abduction bracing with consideration of Botox injection into tight adductors.
  - *Surgery* is indicated if hip shows evidence of subluxation (Reimer index >25%).
  - **Principles:** prevent progression of subluxation by addressing soft tissue (spastic adductors and hip flexors) and bony factors (increased femoral valgus + anteversion) in order to facilitate normal acetabular development thus leading to a stable hip.
- **Adductor + iliopsoas release:**
  - alone, rarely halts progression of subluxation;
  - use in combination with bony procedures.
- **Proximal femoral varus derotational osteotomy (VDRO):**
  - neck-shaft angle of the hip is surgically reduced (to ~115 degrees) and derotation of the excessive femoral anteversion (to ~ 10 –20 degrees of anteversion) is performed to prevent posterior subluxation.
- **Pelvic osteotomy:**
  - superior and posterior deficiency is most common in CP.

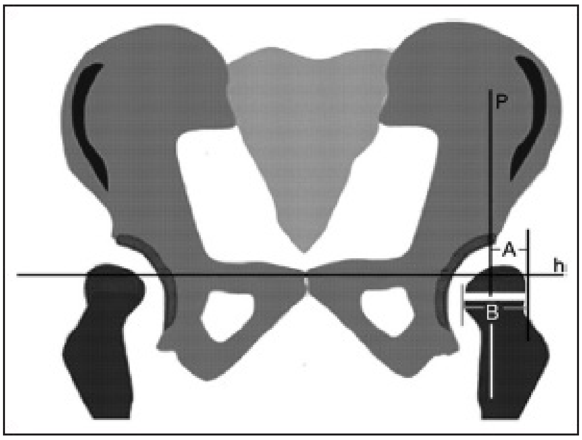

Figure 9.8 Schematic representation showing how the Reimer migration percentage is measured from an AP radiograph. The Hilgenreiner (h) and Perkin (P) lines are drawn. Distance A (the distance from P to the lateral border of the femoral epiphysis) is divided by distance B (the width of the femoral epiphysis) and multiplied by 100 to calculate the Reimer migration percentage (A/B × 100). (Used with permission from Miller F. Hip. In: Dabney K, Alexander M, eds. *Cerebral Palsy.* New York, NY: Springer; 2005:532.)

- Multiple named osteotomies can be used to address dysplastic acetabulum (i.e., Salter, Dega, Pemberton, Chiari, Steel, Ganz) depending on the location of acetabular uncovering and the skeletal maturity of patient (indicated by status of triradiate cartilage).

- **Lever Arm Dysfunction**
  - Results from the disruption of moment generation of a muscle joint complex (despite normal muscle force generation) because of an ineffective moment or lever arm.
  - This is manifested clinically as
    - crouch and loss of power during gait, due to a combination of malrotation
    - loss of bony rigidity
    - loss of stable fulcrum
    - and lever arm shortening.
  - *Intoeing:*
    - causes lever arm dysfunction because malrotation effectively causes lever arm shortening for forward propulsion.

- Can be due to increased femoral anteversion, increased internal tibial torsion, or both.
- Treat with derotational osteotomy of femur or tibia.

- *Pes planovalgus:*
  - foot is externally rotated and patients bare weight on medial border of foot.
  - Lever arm dysfunction is due to malrotation of foot and loss of bony rigidity for push-off.
  - Mild cases can be treated with bracing (SMOs or AFOs).
  - Moderate cases treated with
    - calcaneal lengthening osteotomy
    - peroneus brevis lengthening
    - and medial soft tissue plication OR medial calcaneal slide osteotomy
    - Severe cases treated with subtalar fusion.

- **Specific Gait Abnormalities**
  - Gait abnormalities commonly encountered in ambulatory patients with spastic diplegia, their underlying cause, and treatment are summarized in Table 9.1.
    - *Hip:* In-pointing knees, scissoring, hip flexion contracture.
    - *Knee:* Crouch, jump gait, stiff-knee gait.
    - *Tibia:* Excessive internal or external rotation.
    - *Ankle:* Toe walking, drop foot, equinovarus, forefoot supination, pes planovalgus.

Table 9.1 Summary of the Typical Gait Problems, Primary Causes, and Treatments

Joint Level	Gait Deviation (visual)	Underlying Problem	Correction
Hip	In-pointing knees (and sometimes feet) with scissor gait appearance	Femoral anteversion	Femoral derotation osteotomy (intertrochanteric)
	Reduced hip extension in terminal stance and associated crouch	Hip-flexion contracture	Psoas recession over the brim of the pelvis
	Increased hip adduction or scissoring	Hip adductor contracture and/or spasticity	Hip adductor tenotomy
Knee	Increased knee flexion at initial contact	Hamstring contracture and/or spasticity	Intramuscular lengthening of the hamstrings (medial)
	Increased knee flexion in stance (crouch)	Hamstring contracture and/or spasticity (primary). Note: excessive ankle plantar flexor weakness and length may also be a cause.	Intramuscular lengthening of the hamstrings (medial or medial and lateral)
	Rapid knee extension in loading response and knee hyperextension in mid stance (jump gait)	Contracture and/or spasticity of the ankle plantar flexors	Intramuscular lengthening of the ankle plantar flexors
	Clearance problems in swing related to decreased and/or delayed peak knee flexion in swing (stiff-knee gait)	Increased activity of the rectus femoris in mid swing (confirmation required on surface electromyography) Other causes may be rotational bony malalignment and lower extremity weakness.	Rectus femoris transfer and or intramuscular lengthening
Tibia	Increased internal or external foot progression	Increased internal or external tibial torsion	External or internal distal tibial derotation osteotomy
	Note: Multiple simultaneous rotations may result in normal foot progression with abnormal torsions.		
Ankle	Toe walking or early heel rise in mid stance	Contracture and/or tightness of the ankle plantar flexors	Gastrocnemius lengthening
	Note: toe walking may be a result of increased knee flexion and normal ankle position.		
	Drop foot in swing (excessive equinus in swing)	Anterior tibialis weakness or ankle plantar flexor contracture	Ankle-foot orthosis or gastrocnemius lengthening depending on cause
	Equinovarus	Bony fixed deformity and/or contracture spasticity of the posterior tibialis	Bony deformity correction with Dwyer osteotomy; for dynamic deformity, intramuscular lengthening of the posterior tibialis (Frost)

Joint Level	Gait Deviation (visual)	Underlying Problem	Correction
	Forefoot supination	Spasticity of anterior tibialis and/or imbalance between anterior tibialis and toe extensors	Split anterior tendon transfer (SPLATT)
	Pes planovalgus	Bony deformity and possible peroneal contracture/spasticity	Calcaneal osteotomy or subtalar fusion

(Used with permission from Morrisey RT, Weinstein SL (eds.), Lovell & Winter's Pediatric Orthopaedics, Chapter 15: Cerebral Palsy, Fig 15.4, p. 575.)

- *Foot:* Hallux valgus.
  - Occurs frequently with pes planus, planovalgus, equinovarus.
  - Toe straps within AFOs or nighttime valgus splinting may be helpful.
  - Treat severe deformity with fusion of the first MTP joint.

Myelodysplasia

Introduction

- Myelodysplasia is a nonlethal, complex congenital malformation of the central nervous system that results in long-term motor and sensory dysfunction.
- It is the most common major birth defect affecting 0.9 in 1,000 live births.
- It is due to a failure of the neural crests to close at 3–4 wks of gestation.
- Women of childbearing age should be encouraged to have adequate folic acid intake for prevention.

Classification

- Motor level and functional classifications are summarized in Table 9.2.

Treatment Considerations

- The involvement of a multidisciplinary team of providers is important in treating multi-system manifestations.
- **Neurologic**
  - Neurosurgeons perform surgical closure of myelomeningocele within 48 hrs of birth and shunt for hydrocephalus.
  - Tethered cord can cause progressive scoliosis, a change in functional level, or increasing spasticity.
  - Arnold–Chiari malformation is managed by shunting during infancy and may require later decompression.
- **Urologic**
  - The normal milestones of bladder and bowel control are delayed or absent thus making early catheterization and bowel regimens important.
  - Lower urinary tract dysfunction (i.e., bladder–external sphincter dysfunction) is noted in 90% of patients with myelodysplasia.
  - Kidney reflux and pyelonephritis cause significant morbidity and mortality.
  - Early referral to a urologist is imperative.
- **Gait and Ambulation**
  - Primary predictor of gait and ambulatory function is determined by neurologic level (Table 9.2).
  - Rehab should focus on
    - early mobilization
    - PT
    - bracing
    - standing programs
    - and functional wheelchair fitting
  - In general, L4 level (functional quadriceps) and below is necessary for community ambulation.
  - To support stance and prevent contractures:
    - Hip-knee-ankle-foot orthoses (HKFOs)

• knee-ankle-foot orthoses (KAFOs)

• and ankle-foot orthoses (AFOs)

Table 9.2 Motor Level and Functional Status for Myelomeningocele

Lesion Level	Muscle Involvement	Function	Ambulation
Thoracic/high lumbar	No quadriceps function	Sitter	Some degree until age 13 yrs with HKAFO, RGO
		Possible household ambulatory with RGO	95% to 99% wheelchair dependent as adults
Low lumbar	Quadriceps and medial hamstring function, no gluteus medius, maximus	Household/ community ambulator with KAFO or AFO	Require AFO and crutches, 79% community ambulators as adults, wheelchair for long distances; significant difference between L3 and L4 level, medial hamstring needed for community ambulation
Sacral	Quadriceps and gluteus medius function	Community ambulator with AFO, UCBL, or none	94% retain walking ability as adults
High sacral	No gastrosoleus strength	Community ambulator with AFO, UCBL, or none	Walk without support but require AFO, have gluteus lurch and excessive pelvic obliquity and rotation during gait
Low sacral	Good gastrocnemius-soleus strength, normal gluteus medius, maximus		Walk without AFO, gait close to normal

RGO = reciprocating gait orthosis; UCBL = University of California/Berkeley Lab (orthosis); KAFO = knee-ankle-foot orthosis; AFO = ankle-foot orthosis; HKAFO = hip-knee-ankle-foot orthosis

(Used with permission from Sarwark JF, Aminian A, Westberry DE, Davids JR, Karol LA: Neuromuscular Disorders in Children, in Vaccaro AR (ed): Orthopaedic Knowledge Update 8. Rosemont, IL, American Academy of Orthopaedic Surgeons, 2005, p 678.)

Orthopaedic Management

• Surgery can usually be delayed until other multisystem problems and psychosocial issues addressed.

• **Spine**

- Goal of treatment is to prevent further progression of deformity and improve sitting balance by centering spine over pelvis.
- *Scoliosis*
  - 50–90% of patients will develop scoliosis;
  - incidence depends on level of involvement: almost 100% of thoracic level patients and approximately 60% of L4 level patients develop scoliosis.
  - Curve progression is usually more rapid compared to idiopathic scoliosis.
- *Observation:* curves <30 degrees
- *Bracing:* curves <45 degrees.
  - Bracing generally thought to be “unsuccessful” in achieving curve correction or halting progression but may be used in young patient for improved sitting balance and surgical delay.
  - Rib prominence and pressure sores may be problematic when bracing.
- *Surgery:* curves >50 degrees, curve progression, or spinal imbalance.
  - MRI needed prior to surgery to rule out syrinx, tethered cord, Arnold–Chiari malformation.
  - Preferred method of treatment is anterior + posterior spinal instrumented fusion (posterior fusion alone associated with high rates of pseudarthrosis)
- *Kyphosis*
  - Upper lumbar and thoracolumbar kyphosis is a unique condition found in thoracic level patients with myelomeningocele.
  - Up to 20% have kyphosis >80 degrees at presentation.
  - Deformity may be
    - sharp
    - gradual over multiple levels
    - or associated with congenital vertebral anomalies
  - Progression is expected because of abnormal posterior elements.

            - Progression puts tension on spinal cord that may contribute to tethering.
        - Treatment is predominantly surgical as bracing has no long-term efficacy and may contribute to skin breakdown.
            - Rigid kyphosis is usually managed with posterior osteotomy or excision of vertebral bodies from apex of deformity.
            - Stabilization is best done with segmental fixation placed around nonfunctioning neural elements.
        - Postoperatively, patients immobilized in a TLSO for at least 12 to 18 mo, until healing is ensured.
        - Shunt function must be evaluated prior to kyphectomy because shunt failure can result in acute hydrocephalus and death when the spinal cord is tied off during the kyphectomy.
- **Hip**
    - *Hip flexion contracture:* common but often not severe.
        - If contracture is >40 degrees in an ambulatory patient, consider hip flexor release.
    - *Hip dysplasia/dislocation:*
        - more common in lumbar level compared to thoracic level patients because of greater muscle imbalance.
        - Dislocation occurs in up to 80% of lumbar level patients.
        - Controversy exists on whether a located hip is essential for maximum ambulatory potential.
        - Currently, trend is NOT to reduce dislocated hips in patients with myelodysplasia.
        - No consensus exists on optimal treatment for unilaterally dislocated hips in patients with low-lumbar involvement (i.e., community ambulator).
- **Knee**
    - *Knee extension deformity:*
        - serial flexion casting with goal to achieve 90 degrees of knee flexion.

- Patients with anterior dislocation or anterior subluxation of hamstring muscles are treated with
  - V-Y quadriceps-plasty
  - capsular release
  - and posterior transposition of hamstring muscles.
- *Knee flexion contracture:*
  - can occur in all levels of involvement and tend to progress especially in wheelchair bound patients.
  - Contractures $>$20 degrees can make standing and walking programs difficult.
  - Surgery is recommended if contractures progress and preclude effective bracing.
  - Surgical treatment includes
    - hamstring lengthening
    - posterior capsular release
    - and/or distal femoral extension osteotomy.
- *Knee valgus:*
  - often with associated external tibial torsion and excessive femoral anteversion.
  - This is common in patients with mid-lumbar level involvement due to lack of functional hip abductors and can lead to significant trunk shift when walking with AFOs.
  - This can be addressed by the use of KAFOs or crutches with AFOs.
  - External tibial torsion can be addressed with a tibial derotational osteotomy.

- **Foot**
  - Foot deformity is almost always present in affected individuals with myelomeningocele, and each patient requires individualized treatment depending on the level of paralysis and expected ambulatory potential.
    - About 30% will have rigid clubfoot.

- Equinus contracture is common in thoracic and high-lumbar level patients.
- If surgery is necessary to achieve a plantigrade foot, fusion should be avoided to maintain foot flexibility and to decrease the risk of pressure sores.

- *Calcaneus* foot position can occur with unopposed tibialis anterior contraction (L3–L4 level).
- *Equinovarus, equinus, and calcaneal* foot deformities often are best treated with simple tenotomy rather than tendon transfer, achieving a flail but braceable foot.
- *Valgus* foot deformities are common in L4–L5 level patients.

Other Considerations

- *Latex allergy* is common in these patients, so latex precautions should universally be practiced.
- *Fractures* often present with erythema, warmth, and swelling in insensate child.
- A child with myelodysplasia that presents with hot, swollen extremity should be presumed to have a fracture until proven otherwise.

Duchenne and Becker Muscular Dystrophy

Introduction

- Duchenne and Becker muscular dystrophy (BMD) are genetically based diseases of skeletal muscle that result in progressive weakness.
- Both share similar clinical characteristics, with the main difference being the severity of disease (Becker less severe).

Epidemiology and Genetics

- Duchenne muscular dystrophy (DMD) is the most common muscular dystrophy occurring in 1 in 3,500 live births.
  - It is inherited as an **X-linked recessive** trait thus almost all affected

patients are **male**.

- Up to ⅓ of children acquire the disease as a result of a new mutation.
- BMD is inherited in a similar pattern and occurs in 1 in 30,000 live male births.
  - The defective gene codes for the cell membrane cytoskeleton protein **dystrophin.**
- DMD is associated with mutations that produce an unstable and ineffective protein while BMD is caused by mutations that produce a semi-functional protein.
- Diagnosis was traditionally made by muscle biopsy, which has been replaced by DNA testing as the preferred method.

Clinical Features

- *DMD* presents between 3–6 yrs old.
  - Parents may notice a delay in walking or that the child has become a toe walker.
    - **Calf pseudohypertrophy** is a classic finding due to fatty replacement of calf musculature (seen in 85% of patients).
    - The child may demonstrate frequent tripping and falling and have difficulty running or climbing stairs.
    - Patients display descending, progressive, proximal muscle weakness in the lower extremities.
    - The shoulder girdle and facial muscles become involved later.
    - Death from pulmonary failure occurs in the second or third decade of life.
  - *BMD* has similar, but less severe clinical characteristics that present later in life (age 7 yrs) are less progressive and have less severe pulmonary problems.
    - Patients also have a greater life expectancy.
    - **Gower sign:** the child is placed on the floor and asked to stand.
    - The child “walks” his hands up his knees and thighs to compensate for quadriceps and gluteus maximus weakness in

order to achieve a standing position.

- **Meyeron ("slip through") sign:** shoulder girdle weakness makes it difficult to lift child from beneath the arms as the child has the tendency to slip through truncal grasp.
- **Gait abnormalities:** progressive proximal muscle weakness causes characteristic changes in gait.
  - Patient will balance the head and shoulders behind the pelvis, which results in increased anterior pelvic tilt and increased lumbar lordosis.
  - The child's cadence is decreased and walks with a waddling, wide-based gait with shoulder sway to compensate for gluteus medius weakness.

Treatment

- Goal of treatment is to maintain ambulatory capacity, and to prevent joint contractures and spinal deformity.
- Corticosteroids: currently under investigation (prednisone and deflazacort);
  - Shown to
    - preserve or improve strength
    - prolong ambulation
    - and slow progression of scoliosis
  - But have a high risk of complications including
    - weight gain
    - osteoporosis with associated fractures
    - osteonecrosis
    - myopathy
    - GI symptoms.
- Gene therapy: remains in early investigative stages.
- PT and bracing: directed toward prolongation of functional muscle strength, prevention or correction of contractures by
  - passive stretching

- gait training with orthoses and transfer techniques
- ongoing assessment of muscle strength and functional capacity
- and provides input regarding wheelchair and equipment measurements

- Surgery: indicated when independent ambulation becomes precarious and when joint contractures become painful or interfere with function.
  - The major contractures that are amenable to surgical intervention include
    - equinus and equinovarus contractures
    - knee-flexion contractures
    - hip-flexion
    - and hip-abduction contractures
  - Post-op bracing should be initiated immediately after surgery.
  - Surgery and subsequent bracing may prolong walking ability by 1 to 3 yrs.
- *Spine deformity:* **95% of DMD patients will develop scoliosis** once ambulation ceases.
  - Scoliosis is rapidly progressive.
  - Bracing does not prevent progression and may interfere with already impaired respiration.
  - **Early (curve > 20 degrees) posterior instrumented fusion** recommended before forced vital capacity (FVC) significantly diminishes due to impaired pulmonary function.
  - Surgical correction improves sitting balance and minimizes pelvic obliquity.
  - Careful pre-op evaluation, including pulmonary function studies and cardiology consultation, is mandatory because of associated pulmonary and cardiac abnormalities and risk of malignant hyperthermia.

Spinal Muscular Atrophy

Introduction

- Spinal muscular atrophy (SMA) is a group of disorders characterized by degeneration of the anterior horn cells of the spinal column resulting in motor weakness and atrophy.

Epidemiology and Genetics

- Incidence: 1/6,000 to 1/10,000 live births.
- Inherited as an **autosomal recessive** trait. 1/40–1/50 are carriers of the trait.
- Two genes involved: ***SMN-I*** & ***SMN-II*** (survival motor neuron).
  - All patients with SMA lack *SMN-I*
  - and clinical severity is determined by number of copies of *SMN-II.*
- Preferred diagnostic test is DNA PCR.

Clinical History

- Characterized by symmetric limb and trunk weakness.
  - The lower limbs are more affected than the upper limbs.
  - Proximal muscles are more involved than distal muscles.
  - There is hypotonia and areflexia while sensation and intelligence are normal.
- *Clinical classification*
  - **Type I: Acute Wernig–Hoffman Disease**
    - This is the most severe type with clinical onset between the ages of 0 and 6 mo.
    - It is characterized by marked weakness and hypotonia.
    - Death from respiratory failure occurs between 1 and 24 mo.
    - There is **no orthopaedic intervention** indicated.
  - **Type II: Chronic Wernig–Hoffman Disease**
    - This has less severe clinical manifestations than Type I.
    - Clinical onset is between 6 and 24 mo.
    - These patients are never ambulatory but may live into the fourth

and fifth decades.

- **Type III: Kugelberg–Welander Disease**
  - This is the mildest form of SMA with clinical onset between 2 and 10 yrs.
  - These patients are ambulatory until late childhood/early adolescence with a normal life expectancy.

Treatment

- There is no effective medical treatment (i.e., steroids).
- **Lower extremity contractures**
  - Result of replacement of muscle by fibrous tissue.
  - They occur most frequently as the child becomes wheelchair bound.
  - Constant sitting posture promotes hip and knee flexion contractures.
  - They may be delayed by the use of orthoses.
  - Surgical contracture release is indicated for those with ambulatory potential.
- **Hip dislocation**
  - Prevention of dislocation is important in order to maintain sitting comfort and balance.
  - Periodic AP pelvis radiographs are recommended starting in mid to late childhood.
  - Treatment for hip dislocation is controversial because of high recurrence rate of dislocation and poor correlation of hip dislocation with pain/discomfort.
  - Treatment should be individualized to each patient with the presence of pain as a guide.
- **Scoliosis**
  - Occurs in a vast majority of patients that survive into adolescence (those who become wheelchair bound).
  - Severe scoliosis will have a detrimental effect on pulmonary function.

- Curve progression is inevitable.
- Bracing is ineffective in halting curve progression but may be useful in helping with sitting balance.
- Surgical criteria for posterior instrumented fusion:
  - curve >40 degrees
  - flexible curve as determined by bending radiographs
  - and FVC >40% normal
- Patients will experience a decline of upper extremity function post-op, which may affect an ambulatory child's ability to walk with assistive devices.
- VEPTR or growing rods may be useful for young children (2–3 yrs) with severe deformity in order to delay definitive fusion.

Hereditary Sensory Motor Neuropathy

Introduction

- Hereditary sensory motor neuropathy (HSMN) refers to a group of inherited neuropathic disorders, which cause progressive peripheral neuropathy.

Clinical Types

- *HSMN Type I (Charcot—Marie–Tooth disease):* most common HSMN.
  - Has variable inheritance but **autosomal dominant** is most common.
  - Commonly caused by a mutation in chromosome 17p11, which encodes for **PMP-22** (peripheral myelin protein-22).
  - The disease is clinically characterized by **peripheral demyelination** with diminished motor conduction causing peroneal muscle atrophy and absent deep tendon reflexes.
- *HSMN Type II:* clinically similar to Type I but less severe and later age of onset.
  - **Autosomal dominant** inheritance is most common.

- Results in progressive **axonal degeneration with an intact myelin sheath.**
- Results in mildly abnormal motor conduction manifested as less severe weakness and intact deep tendon reflexes.

- *HSMN Type III (Denerine–Sottas disease):* **autosomal recessive** mode of inheritance.
  - Associated with a mutation in the **MPZ gene**.
  - Manifests in infancy and is more severe than HSMN Type I or II.
  - Clinically characterized by a demyelinating disease like HSMN Type I resulting in
    - severely diminished motor conduction
    - peripheral nerve enlargement
    - nystagmus
    - ataxia
    - and loss of walking ability by maturity.

Treatment

- Patients most commonly present with gait and foot abnormalities due to distal muscle weakness of intrinsic and extrinsic foot muscles.
- **Pes cavovarus**
  - Results from
    - tight plantar fascia
    - weak tibialis anterior
    - weak peroneals
    - week intrinsics
    - and normal FDL and FHL
  - Peroneus longus is relatively stronger than p. brevis and a. tibialis resulting in **plantar flexed first ray, which leads to a varus hindfoot**.
    - Initially, the deformity is flexible but will eventually become

fixed without treatment.
    - **Coleman block test** is used to distinguish a flexible from a fixed deformity.
  - *Surgery:* goal is to provide a flexible, plantigrade foot.
    - Plantar fascia release with PTT transfer to foot dorsum or split PTT transfer.
    - Forefoot cavus is addressed by plantar fascia release with possible midfoot dorsiflexion osteotomies.
    - Hindfoot equinus is addressed with tendo-Achilles lengthening (TAL).
    - Fixed hindfoot varus is addressed with calcaneal osteotomy (Dwyer).
- **Hip dysplasia**
  - Occurs in 5–10% of patients with HSMN but more commonly occurs in patients with HSMN Type I.
  - Results from weak hip abductors and extensors.
  - Annual AP pelvis radiograph is recommended to monitor.
  - *Surgery:* range depends on severity:
    - soft tissue releases
    - proximal femoral osteotomies
    - pelvic osteotomies
- **Scoliosis**
  - May be seen in up to 35% of patients with HSMN.
  - Incidence increases to 50% in skeletally mature patients.
  - Occurs more commonly in girls and with HSMN Type I.
  - Curve pattern is similar to idiopathic scoliosis but kyphoscoliosis is more common.
  - Bracing may be used to attempt to halt curve progression.
  - Instrumented posterior spinal fusion is recommended for curves 45–50 degrees.

- Intra-op neuro-monitoring **(SSEPs) may show no signal transmission** because of demyelination of peripheral nerves.

- **Upper extremity**
  - The hand and upper extremity is involved in up to ⅔ of patients.
  - There is **intrinsic, thenar, and hypothenar wasting.**
    - This results in clawing, diminished pinch power, and limited thumb abduction.
  - OT may be helpful.
  - *Surgery:*
    - FDS transfer to restore opposition
    - nerve compression release
    - soft tissue contracture release
    - joint arthrodesis

Friedrich Ataxia

Introduction

- Friedrich ataxia (FA) is the most common form of **spinocerebellar degenerative disease**.
- It occurs in 1/50,000 live births and is inherited as an **autosomal recessive** trait.
- It is associated with a high incidence of scoliosis and pes cavovarus.

Clinical History

- Clinical "triad" of ataxia, areflexia, and positive Babinski sign.
- The age of onset is before 25 yrs.
- There is
  - a progressive ataxia of the limbs and gait
  - dysarthria

- absent deep tendon reflexes of the knee and ankle
- and slowed nerve conduction velocities of the upper extremities
- Patients are wheelchair bound by the second or third decade.
  - Proximal muscles are more involved than distal muscles and lower extremities are more affected than upper extremities.
  - Gluteus maximus (hip extensor) is usually the first muscle to become involved.
- *Genetics:* there is a defect in chromosome 9q13 with a loss of expression of the *frataxin* protein.
  - The mutation is related to a trinucleotide repeat GAA.
  - The age of onset is related to the number of GAA repeats; the more repeats, the earlier age of onset.
  - DNA testing is the diagnostic test of choice.

Treatment

- **Pes cavovarus**
  - Common in patients with FA.
  - The deformity is slowly progressive and tends to become rigid.
  - Not responsive to bracing.
- *Surgery:* reserved for ambulatory patients.
  - Treat with
    - TAL
    - PT transfer or tenotomy
    - and triple arthrodesis (for rigid deformities).
- **Scoliosis**
  - Occurs in almost all patients with FA.
  - The incidence of curve progression is related to the age of disease onset.
    - Disease onset
      - $<$10 yrs and scoliosis onset $<$15 yrs→curve progression $>$60 degrees.

- $>$10 yrs and scoliosis onset $>$15 yrs→curve progression $<$40 degrees.

- Curve patterns are similar to idiopathic scoliosis (unlike other neuromuscular curves).
- Orthosis is recommended for ambulatory patients with 25–40 degree curves.
- *Surgery:* instrumented posterior spinal fusion for curves $>$60 degrees with evidence of progression.

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INFECTIONS

ABIGAIL ALLEN • JANAY MCKIE

Key point: Evaluate infection in context of local epidemiologic patterns

Pathophysiology

- Musculoskeletal infections are usually spread hematogenously from ear, oropharynx, respiratory, GI or GU tracts as a portal of entry.
- A less likely, but possible, source of infection includes infection by direct extension (e.g., skin infection, penetrating injury).
- Metaphyseal bone and/or the joint space is usually involved.
- The natural history of the infection depends on organism virulence and host resistance.

Physical Exam

- The physician examining a patient for presumed infection should ask the following questions:
  - General appearance of child—do they look ill?
  - Is there spontaneous movement of the limb or pseudoparalysis of the limb?
    - In what position is the affect limb held?
  - Is the child able to ambulate?
  - Is swelling, erythema, increased temperature of the affected area present?

Evaluation

- Evaluation of the patient should include
  - complete blood count with differential (CBC),
  - erythrocyte sedimentation rate (ESR),
  - C-reactive protein (CRP) level,
  - and blood cultures.
- Imaging must be done as well.
  - Adequate imaging includes plain radiographs or ultrasound with bone scan or MRI.
- Biopsy and culture of site can be considered if there is difficulty in isolating the organism involved in the infection or if ruling out other causes of patient symptoms (e.g., tumor).
  - It is recommended to obtain all necessary cultures (blood and/or wound) before starting antibiotics.

Differential Diagnosis

- Septic arthritis
- Osteomyelitis
- Transient synovitis

Septic Arthritis

Introduction

- Septic arthritis is defined as joint inflammation due to an infection involving synovial joints.
- It occurs mostly in children less than 2 yrs old and is more common in boys than girls.
- Organisms causing septic arthritis vary by age group.
  - In neonates, group B Streptococcus, *Staphylococcus aureus,* and gram-negative bacilli are the usual cause.

- In children 1 mo old to adolescent aged patients, *S. aureus, Streptococcus pneumonia,* and *Streptococcus pyogenes* are the usual organisms.
- In older adolescents, there should be a high suspicion of *Neisseria gonorrhoeae.*

- In non-immunized patients, *Haemophilus influenzae* B must be ruled out.

Natural History

- The joint is exposed to the enzymes produced by bacteria and leukocytes.
- Progressive proteoglycan loss and collagen degradation occurs in the cartilage when there is continued exposure to these enzymes.
- Delay or no treatment leads to residual joint deformity.

Clinical History

- Be suspicious of patients who present with signs consistent with Kocher criteria:
  - fever
  - unwilling to bear weight on the leg
  - ESR $>$ 40 mm/hr
  - Leukocytosis $>$ 12,000
- In the neonate, however, there will be few clinical signs (e.g., no fever and no clinically ill appearance).
  - In this patient population, look for loss of spontaneous movement of the extremity and posturing of the joint at rest.
  - The infant/child presents with fever, ill appearance, swollen and tender joints that resist movement.

Imaging

- Radiographs can appear normal early in the infection but soft tissue edema, joint space widening, subluxation/dislocation of involved joint can be noted.
  - During late infection, radiographs may be positive for epiphyseal

ischemic necrosis and associated metaphyseal/epiphyseal osteomyelitis.

- Bone scan and MRI are useful in identifying associated osteomyelitis, if present.
- Ultrasound is often used to determine the presence of effusion.
- It is very important to combine the information gained from imaging with the clinical picture.

Diagnosis

- Joint aspiration yielding a leukocyte count above 50,000 and PMNs predominating is suggestive of septic arthritis.
- Gram stain and culture of the joint aspirate along with blood cultures are crucial to isolating an organism.

Management

- Joint drainage (arthroscopic versus open techniques) is the key to treating septic arthritis.
- After cultures are drawn, the intravenous antibiotic that is statistically most likely to be effective is started.
- The infectious disease team is involved and generally makes the decisions on choice and length of antibiotic treatment.
  - Once culture sensitivities return, the antibiotic can be altered accordingly.
- Intravenous antibiotics are usually continued for 3–21 d.
- Special attention should be given to clinical improvement in the patient (e.g., reduction in fever, local inflammation and CRP response).
- Failure to improve clinically requires further investigation and possibly a repeat drainage.
- The patient is often started on oral antibiotics for 3–4 wks after clinical improvement noted.

OSTEOMYELITIS

Introduction

- Osteomyelitis is an infection of bone.
- Organisms usually involved include *S. aureus* (most common), Group A Streptococcus, *S. pneumonia,* and Group B beta-hemolytic streptococcus.

Natural History

- The natural history is determined by organism virulence, resistance of the host, and age of onset.
- The infection starts in the metaphysis and its spread depends on age.
  - In an infant, the metaphysis and epiphysis share a common blood supply and therefore the infection spreads into the joint.
  - In a child, the infection spreads into the adjacent metaphyseal cortex and forms an extramedullary abscess.
  - In the mature adolescent, the infection spreads throughout the medullary cavity.

Presentation

- *Acute*
  - Approximately 50% of affected children are less than 5 yrs old and one-third are less than 2 yrs old.
  - This is usually secondary to trauma to the metaphysis and concomitant bacteremia.
  - The insult initiates osteomyelitis and
    - produces local pain, swelling, warmth, erythema, tenderness
    - in addition to fever and malaise.
  - Additionally, patients will have elevated CRP and ESR with leukocytosis.
  - Patients with osteomyelitis can be at risk for septic arthritis in the following areas because the metaphysis lies within the joint capsule:
    - proximal femur and hip
    - proximal humerus and glenohumeral joint

        - lateral distal tibia and ankle
        - radial neck in the elbow
    - Radiographs are
        - Initially: normal
        - after 48 hrs: progress to show soft tissue swelling
        - after 5–7 d: periosteal new bone formation
        - after 10–14 d: osteolytic changes in bone
    - It is important to check for the presence of free air in the tissue.
        - Comparison views are obtained as needed.
        - Bone scan can be essential when radiographs are normal but high clinical suspicion exists.
        - A cold scan can suggest late or severe infection with osteonecrosis.
        - Ultrasound or MRI can also be obtained to localize site of infection and evaluate for any abscess.
    - The organism causing osteomyelitis is isolated via blood culture or aspiration of the infected site.
    - Management of acute osteomyelitis is best with intravenous antibiotics without drainage if there is no evidence of abscess.
        - The infectious disease team should be consulted.
        - Empiric antibiotics based on known bacteria endemic to the area are started until culture results become available.
        - In neonates, gentamicin/cefotaxime should be added for empiric treatment.
        - If MRSA is suspected, the patient should be started on vancomycin.
        - Formal drainage should be performed if an abscess is present or if there is no clinical improvement after 48 hrs of empiric antibiotics.
- *Subacute*
    - Subacute osteomyelitis is a bone infection for greater than 2–3 wks.

- It is a residual of acute osteomyelitis that has been contained but not eradicated.
- Patients present with
  - local swelling
  - warmth
  - and tenderness with or without limp.
- Unlike acute osteomyelitis, there is little systemic response.
  - Radiographs will show a lesion in bone.
  - This lesion can be confused with a primary bone tumor.
- Subacute osteomyelitis is managed with intravenous antibiotic treatment.
  - Drainage and culture should also always be performed in the following circumstances:
    - atypical bone lesion and/or concern for neoplasm
    - immunologically impaired children
    - or persistant symptoms despite antibiotic treatment.

- *Chronic*
  - Chronic osteomyelitis is a bone infection for greater than 3 wks.
  - The extent of disease must be determined with radiographs, MRI, and CT scans.
  - Operative removal of dead bone (sequestrectomy) and removal of infected tissue (saucerization) is the treatment of choice for chronic osteomyelitis.
  - Complications associated with this form of bone infection include
    - systemic infection
    - pathological fracture
    - sequestrum formation
    - and growth disturbance.

Transient Synovitis of the Hip

Introduction

- Transient synovitis is a noninfections inflammatory condition that must be differentiated from septic arthritis of the hip.
  - This differentiation is determined by evaluating a patient in accordance to the Kocher criteria (refer to above).
  - There is a higher probability for septic arthritis when patient has multiple features of the Kocher criteria.
  - With transient synovitis, there are less signs of systemic illness and joint inflammation.
  - The patient
    - is more than likely able to ambulate,
    - has less pain with hip ROM,
    - and has moderate relief with NSAIDs.
- This disease entity is best managed with scheduled NSAIDs and close follow-up.
  - The patient should return for further treatment immediately if the condition worsens.

General Treatment Principles for Pediatric Musculoskeletal Infections

- Early treatment is the best treatment.
- Intravenous antibiotics should be the initial treatment then oral antibiotic treatment should be transitioned to when the disease is under control.
- Duration of antibiotics is based on severity and potential for disability that the infection poses, the rapidity of response to treatment, and serial determinations of inflammatory markers (i.e. CRP).
- Surgical treatment is indicated when gross abscess is present or if appropriate empiric antibiotic therapy leads to only minimal

clinical/laboratory improvement.

- Operative drainage options:
  - needle aspiration
  - arthroscopic decompression
  - open debridement

Atypical Conditions to Keep in Mind

Chronic Recurrent Multifocal Osteomyelitis

- Chronic recurrent multifocal osteomyelitis (CRMO) is defined as multiple lesions in metaphyseal bone due to an inflammatory process of unknown etiology.
- The patient has elevation in WBC.
- The symptoms wax and wane over several years.
- CRMO is treated with NSAIDs, not antibiotics.

Postgastroenteritis Arthritis

- Postgastroenteritis arthritis is joint pain after infection with intestinal pathology. Stool cultures are positive.
- Typical organisms are
  - *Salmonella*
  - *Shigella*
  - *Yersinia*
  - *Campylobacter*

Lyme Arthritis

- This disease is usually suspected in patients with a history of tick bite in endemic area in the setting of joint pain.
- The Lyme titer is positive.
- Erythema migrans (typical rash) can be found in conjunction with

joint symptoms, but is often not.

Viral Arthritis

- Viral arthritis usually presents as joint pain in multiple small joints.
- Of note, parvovirus infection can mimic septic arthritis

Sickle Cell Disease

- Patients with sickle cell disease are more likely to have pain crisis than osteomyelitis.
  - However, osteomyelitis can occur as a result of the microvascular disease as well as the bony infarcts characteristic of this disease.
  - In the setting of osteomyelitis, the patient will appear systemically ill and have a high fever.
- The diagnosis must be confirmed with aspiration.
- *S. aureus* and *Salmonella* are the organisms of interest.
- Bone scan, sequential bone marrow test, or MRI with contrast can aid in distinguishing between bone infarct and osteomyelitis.
- Surgical drainage is the preferred treatment.

Puncture Wounds

- Puncture wounds can lead to osteomyelitis or septic arthritis depending on location of wound.
- *Pseudomonas* is the usual organism involved.
- Confirmed infection should be treated with surgical debridement and IV antibiotic coverage.

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ADOLESCENT ATHLETE

MATTHEW D. MILEWSKI

Introduction

- Athletic participation has increased in children and adolescents over the last 30 yrs.
- The skeletally immature athlete is at particular risk for overuse injuries along with a number of unique orthopaedic problems.

Shoulder Girdle Fractures

- Clavicle fractures are common in young athletes.
  - The medial clavicle physis is last to ossify at age 22–25 yrs of age
  - the lateral clavicle physis closes at approximately 19 yrs of age.
- Physeal fractures can mimic sternoclavicular (SC) and acromioclavicular (AC) dislocations.
- Most clavicle fractures can be treated nonoperatively in young athletes.
  - Indications for operative treatment of clavicle fractures in young athletes include
    - open fractures
    - tenting of the skin
    - neurovascular compromise
    - in the setting of polytrauma
- The acromion has multiple ossification centers and defects in ossification can also mimic fracture (Os acromiale).

- This is present in 3–8% of the population and is commonly bilateral.

Shoulder Injuries in Young Overhead Athletes

- Shoulder injuries have increased in young overhead athletes as specialization has increased.
- **Little Leaguer shoulder** refers to a stress fracture of the proximal humeral physis.
  - It is most common in high-performance male pitchers between the ages of 11 and 13.
  - They generally present with lateral tenderness over the proximal humerus and painful external rotation.
  - Radiographs can show widening of the proximal humeral physis
    - with late findings of fragmentation, sclerosis and cystic changes.
  - Contralateral films are necessary to compare physeal widening.
  - MRI can be useful if radiographs are inconclusive.
  - Treatment is nonoperative with rest from pitching and adequate conditioning prior to resuming throwing.
  - Little league pitchers can also suffer from glenohumeral internal rotation deficit (GIRD) and may be related to both posterior capsular contracture and increased humeral retroversion.

Elbow Injuries in Young Overhead Athletes

- Adolescent overhead throwers are at risk for osteochondritis dissecans (OCD) and medial epicondylar stress fractures.
- **Little leaguer's elbow** is a traction apophysitis of medial epicondyle.
  - They will present with
    - swelling of the medial elbow
    - flexion contracture

    - and tenderness of the medial epicondyle that are exacerbated by pitching.
  - Radiographs can show
    - physeal widening
    - fragmentation
    - or even frank fracture of the medial epicondyle.
  - MRI can be useful if radiographs are inconclusive.
- **Osteochondritis dissecans** of the capitellum is also common in overhead throwing athletes (generally older adolescents greater than 13 yrs of age).
- **Panner disease** is an osteochondrosis of the capitulum in younger children between ages 5 and 12 yrs of age.
  - They both typically present with lateral elbow pain, tenderness, and flexion contracture along with mechanical symptoms if loose bodies have developed.
  - Prognosis is improved in younger patients, especially those with Panner disease.
- Treatment involves rest mainly from overhead throwing.
- OCD lesions that are displaced or fail conservative treatment may require fragment fixation or debridement if not salvageable.

Knee Injuries

- Knee injuries are very common in adolescent athletes.
- The differential diagnosis for a young athlete with knee pain can include
  - ACL injuries
  - meniscal injuries
  - OCD lesions
  - unique fractures: tibial spine or tibial tubercle fractures
  - osteochondroses: Osgood–Schlatter disease, and patellar instability.

- **Tibial spine fractures** were once thought to be much more common than **ACL injuries** in skeletally immature patients but with increased athletic participation, awareness of these injuries and improvements in MRI access and imaging; the rate of ACL injuries has increased significantly.
  - ACL deficiency in children is associated with increased risk of meniscal and chondral damage.
  - ACL reconstruction techniques in skeletally immature patients vary based on the patient's age.
- A physeal-sparing combined intra-articular/extra-articular reconstruction technique using IT band can be used for very young patients.
  - Treatment
    - All epiphyseal reconstruction techniques can be used for children slightly older (8–12 yrs of age).
    - Traditional trans-physeal reconstruction techniques can be used as the patient approaches skeletal maturity.
- **Discoid menisci** are very commonly diagnosed in adolescent athletes.
  - Bilateral discoid menisci are common (20%).
  - Classified by Watanabe
    - Type 1: stable, complete
    - Type 2: stable, incomplete
    - Type 3: unstable, Wrisberg variant, lacks traditional posterior meniscal attachments).
  - **Torn discoid menisci** that have failed conservative treatment are generally treated with arthroscopic saucerization with meniscal repair if an unstable or Wrisberg variant.
- OCD is also very common in adolescent athletes.
  - They are usually found on lateral portion of medial femoral condyle.
  - Mechanical symptoms may indicate a loose body.
  - Wilson's sign is pain with internal rotation with extending the knee

from 90 to 30 degrees.

- Prognosis and treatment are based on the patient's age and lesion stability.
- MRI is useful in assessing for
  - integrity of articular cartilage surface
  - fluid behind the lesion
  - and associated subchondral changes.
- Treatment
  - Conservative treatment includes non-weightbearing with immobilization ranging from traditional casting to newer unloader brace for a period of 3–6 mo.
  - Operative intervention for in situ lesions can range from antegrade or retrograde drilling to stimulate healing to fixation with metal or bioabsorbable screws.
  - Displaced lesions with insufficient bone stock for fixation or unsalvageable lesions may require
    - microfracture
    - OATS plugs
    - ACI
    - or osteochondral allografting depending on the lesion.

- **Patellar instability** is another common injury in adolescence.
  - Traumatic first time dislocations can generally be treated nonoperatively with
    - temporary immobilization
    - bracing
    - and physical therapy.
  - If mechanical symptoms accompany a first time patellar dislocation, a loose body or osteochondral fracture (generally from the medial facet of the patella or the lateral trochlea/femoral condyle) may have accompanied the dislocation and may be an indication for acute operative treatment.

- **Chronic patellar instability** that has failed conservative treatment including physical therapy and bracing may necessitate operative treatment.
  - Operative options will depend on the patient's skeletal maturity.
  - Options in skeletally mature patients include
    - diagnostic arthroscopy,
    - medial patellofemoral ligament (MPFL) reconstruction,
    - and possibly tibial tubercle osteotomy (anteromedialization osteotomy or Fulkerson osteotomy)
      - These options may not be possible in skeletally immature patients, and non–anatomic reconstruction techniques are sometimes needed such as the Roux–Goldthwaite procedure or Galeazzi procedure.
      - Multiple options now exist for MPFL reconstruction to avoid a tunnel that might damage the medial portion of the distal femoral physis.

Pelvis Avulsion Injuries

- Apophyseal avulsion fractures are common in adolescent athletes around the pelvis.
- Common fractures include
  - ASIS (pulled by sartorius)
  - AIIS (rectus femoris)
  - ischial tuberosity (hamstrings)
  - and lesser trochanter (iliopsoas).
- Treatment is generally conservative with rest.
- Surgery is rarely indicated.

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