Fundamental Critical Care Support

Sixth Edition

Society of Critical Care Medicine
The Intensive Care Professionals

Fundamental Critical Care Support

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PREFACE

Pioneers in critical care medicine drafted the first edition of the Fundamental Critical Care Support (FCCS) textbook when the concept of FCCS training was first conceived more than a quarter of a century ago. Over the years, the book has served as a resource for learners and teachers in critical care. With the sixth edition, we continue the tradition and build on the efforts and successes of all previous authors.

The purpose of this book is to serve as a resource for teaching the basic concepts in the recognition of the critically ill patient and provision of the support needed until a critical care specialist arrives.

The FCCS course focuses on the initial assessment and management of the critically ill patient. Changes were made throughout the book to reflect new concepts, guidelines, and practices. All of these changes were made after researching the latest evidence-based literature available at the time of publication.

The book chapters use both an organ system-based and problem-based format. The chapters revolve around commonly encountered case scenarios. Many callout boxes are included, and they are designed to direct the reader's attention to specific and important concepts for that chapter. International experts were consulted, and feedback from learners and educators throughout the world was taken into consideration. In the end, we tried to produce a textbook that addresses the needs of different populations and various countries.

The journey to publication of this edition included many Society of Critical Care Medicine staff members and behind-the-scenes workers who spent countless hours editing the book and tracking all the logistics, making sure we have an excellent end product. For all of them, we are thankful. We are also honored and thankful to have such a distinguished group of experts to help compose and edit the sixth edition chapters. Many have been practicing and teaching critical care, as well as leading FCCS courses, for many years. They selflessly offered their time, effort, and expertise in editing this book.

The sixth edition of the FCCS textbook is a key component of the FCCS program, which continues to expand and grow to meet the needs of critical care learners and educators for the present and future generations.

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CHAPTER 1

RECOGNITION AND ASSESSMENT OF THE SERIOUSLY ILL PATIENT

Objectives

- Explain the importance of early identification of patients at risk for life-threatening illness or injury and the importance of early intervention.
- Recognize the early signs and symptoms of critical illness.
- Discuss the initial assessment and early stabilization and treatment of the critically ill or injured patient.

Case Study

A 54-year-old woman with diabetes was admitted with an intra-abdominal abscess following laparoscopic cholecystectomy. She underwent placement of a drain by the interventional radiology department. Two hours later, she developed a temperature of 39.4°C (103°F), heart rate of 128 beats/min, and blood pressure of 80/40 mm Hg.

– What do you detect?

– Which aspects of the physical examination would you concentrate on initially?

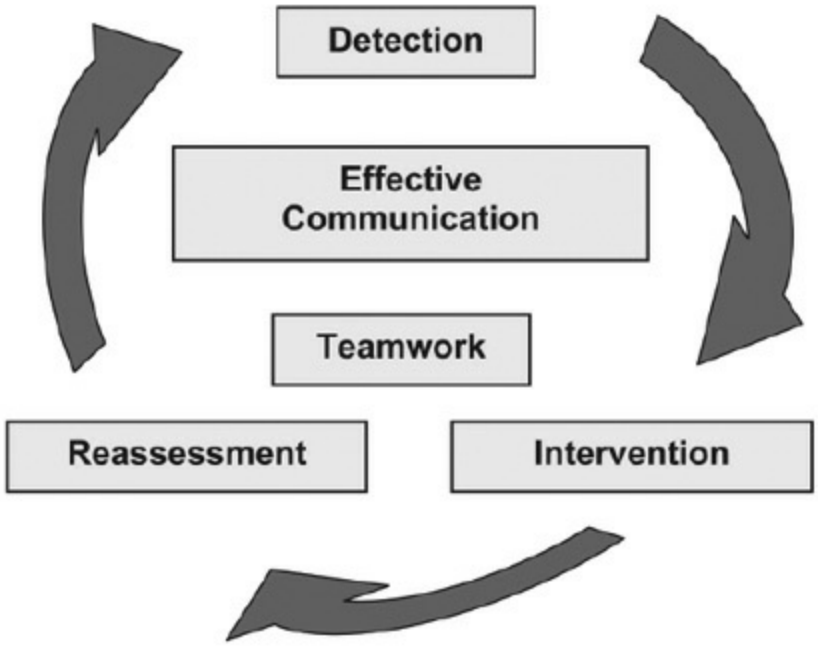
– Which laboratory and radiographic investigations would you order for this patient?

I. INTRODUCTION

"An ounce of prevention is worth a pound of cure" is a common idiom that often applies to the care of critically ill patients. Early identification of patients at risk for life-threatening illness makes it easier to manage them initially and prevents further deterioration. Many clinical problems, if recognized early, can be managed with simple

measures such as supplemental oxygen, respiratory therapy interventions, intravenous fluids, or effective analgesia. The early identification of patients in trouble allows clinicians to identify the main physiological problem, determine its underlying cause, and begin specific treatments. The longer the interval between the onset of an acute illness and the appropriate intervention, the more likely it is that the patient's condition will deteriorate, even to cardiopulmonary arrest. Several studies have demonstrated that physiological deterioration precedes many cardiopulmonary arrests by hours, suggesting that early intervention could prevent the need for resuscitation, admission to the ICU, and other sentinel events. Many hospitals are using rapid response systems to identify patients at risk and begin early treatment. (See **Appendix 1** for further information on the organization and implementation of a rapid response systems.) The purpose of this chapter is to describe the general principles involved in recognizing and assessing acutely ill patients. This chapter also introduces the key Fundamental Critical Care Support course learning and management concept of **DIRECT**: detection, intervention, reassessment, effective communication, and teamwork (**Figure 1-1**).

Figure 1-1. DIRECT Methodology



Detection: Using the history, physical exam, and the behavioral, cardiovascular and respiratory system changes, the critical care team is alerted to the patient's physiological status. These items then guide the appropriate laboratory and radiographic evaluations to establish a working/presumptive diagnosis, differential diagnosis, and worst possible diagnosis.

Intervention: This is the process of treating and correcting the disease or injury while keeping in mind the critical care maxim to minimize morbidity and prevent mortality.

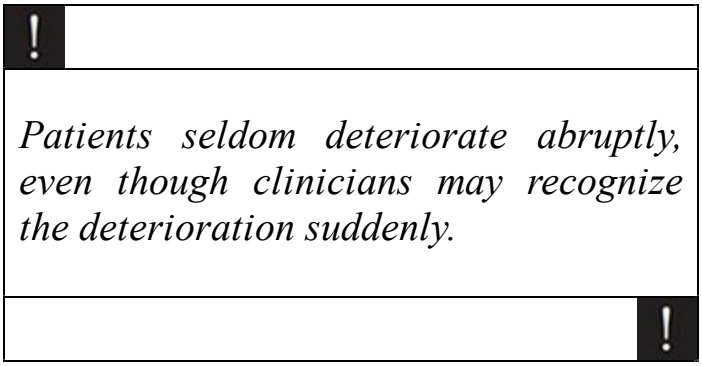
Reassessment: This ensures the treatment is appropriate for the severity of the disease and/or injury.

Effective Communication: The greatest source of injury and death in healthcare is communication error. The more complicated the patient, the more important it is for everyone to communicate their perspective to the team so that multiple and often time-sensitive tasks can be done expertly and promptly.

Teamwork: The patient does best when all members of the healthcare team bring their specialized training to work together synergistically to care for the needs of the critically ill or injured patient.

Reproduced from Madden MA, ed. *Pediatric Fundamental Critical Care Support*. 2nd ed. Mount Prospect, IL: Society of Critical Care Medicine; 2013.

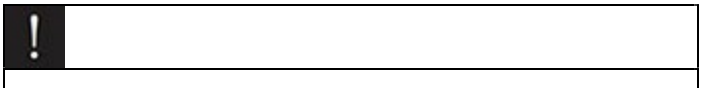
II. RECOGNIZING THE PATIENT AT RISK



Patients seldom deteriorate abruptly, even though clinicians may recognize the deterioration suddenly.

Recognizing that a patient is seriously or critically ill is usually not difficult. It may be more challenging, however, if the patient is in the very early stages of the process. Young and otherwise healthy patients are usually much slower to exhibit the typical signs and symptoms of acute illness than elderly patients or those with comorbidities and/or impaired cardiopulmonary function. Individuals who are immunosuppressed or debilitated may not demonstrate a vigorous and clinically obvious inflammatory response. Some conditions, such as cardiac arrhythmias, do not evolve with progressively worsening and easily detectable changes in physiology but rather present as an abrupt change of state. In most circumstances, a balance exists between the patient's physiologic reserve and the acute disease. Patients with limited reserve are more likely to be susceptible to severe illness and to experience greater degrees of organ-system impairment. Therefore, identifying patients at risk for deterioration requires assessment of their background health, their current disease process, and their current physiological condition.

A. Assessing Severity

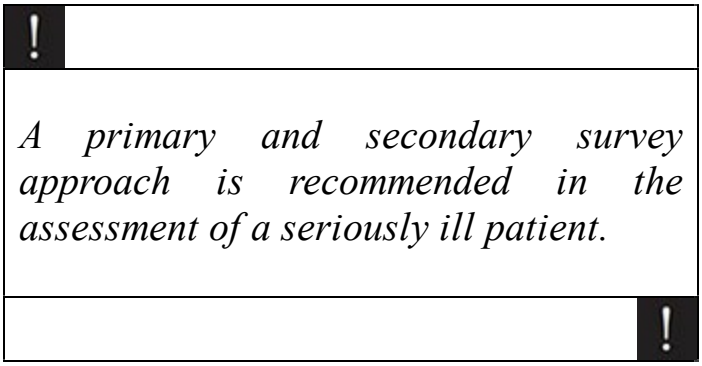


Even normal vital signs may be early indicators of impending deterioration if they differ from prior measurements.

"How sick is this patient?" is one of the most important questions a clinician must answer. Determining the response requires the measurement of vital signs and other specific physiological variables (**Appendix 1**). Acute illness typically causes predictable physiological changes associated with both disease-specific and general clinical signs. For example, a patient's physiological response to a bacterial infection may result in fever, delirium, shaking chills, and tachypnea. The most important step is to recognize these signs and initiate physiologic monitoring in order to quantify the severity of disease and take appropriate action. Sick patients may present with confusion, irritability, impaired consciousness, or a sense of impending doom. They may appear short of breath and demonstrate signs of a sympathetic response, such as pallor, sweating, or cool extremities. Symptoms may be nonspecific, such as nausea and weakness, or they may identify the involvement of a particular organ system (for example, chest pain). Therefore, a high index of suspicion is required when measuring vital signs: pulse rate, blood pressure, respiratory rate, oxygenation, temperature, and urine output. Clinical monitoring helps to quantify the severity of the disease process, tracks trends and rates of deterioration, and directs attention to those aspects of physiology that most urgently need treatment. The goals at this stage of assessment are to recognize that a problem exists and to maintain physiological stability while pursuing the cause and initiating treatment.

Tachycardia in response to physiological abnormalities (ie, fever, low cardiac output) may be increased with pain and anxiety or suppressed in patients who have conduction abnormalities or are receiving ß-blocker medications.

B. Making a Diagnosis



Making an accurate diagnosis in the acutely ill patient often must take second place to treating life-threatening physiological abnormalities. It is important to ask the question, "What physiological problem needs to be corrected now to prevent further deterioration of the patient's condition?" Correcting the problem may be as simple as providing oxygen or intravenous fluids. There may not be sufficient time for a lengthy pursuit of a differential diagnosis initially if the patient is seriously ill and needs to be stabilized. However, an accurate diagnosis is essential for refining treatment options once physiological stability is achieved. The general principles of taking an accurate history, performing a brief, directed clinical examination followed by a secondary survey, and organizing laboratory and radiographic investigations are fundamentally important. Good clinical skills and a disciplined approach are required to accomplish these tasks.

III. INITIAL ASSESSMENT OF THE CRITICALLY ILL PATIENT

A framework for assessing the acutely ill patient is provided in **Table 1-1** and discussed below. Further information on specific issues and treatments can be found in later chapters of this text.

A. History

The patient's history usually provides the greatest contribution to diagnosis. Often the current history, past medical history, and medication list must be obtained from family members, caregivers, friends, neighbors, or other healthcare providers. The risk of critical illness is increased in patients with the following characteristics:

- Emergency admission (limited information)
- Advanced age (limited reserve)
- Severe coexisting chronic illness (limited reserve, limited options for

management)

- Severe physiological abnormalities (limited reserve, refractory to therapy)
- Need for, or recent history of, major surgery, especially an emergency procedure
- Severe hemorrhage or need for a massive blood transfusion
- Deterioration or lack of improvement
- Immunodeficiency
- Combination of these factors

Table 1-1 Framework for Assessing the Acutely Ill or Injured Patient

	PHASE I **Initial Contact—First Minutes** (Primary Survey) What is the main physiological problem?	**PHASE II** **Subsequent Reviews** (Secondary Survey) What is the underlying cause?
History	**Main features of circumstances and environment** • Witnesses, healthcare personnel, relatives • Main symptoms: pain, dyspnea, altered mental status, weakness • Trauma or no trauma • Operative or nonoperative • Medications and/or toxins	**More detailed information** • Present complaint • Past history, chronic diseases, surgical procedures • Hospital course (if applicable) • Psychosocial and physical independence • Medications and allergies • Family history • Ethical or legal issues, code status • Systems review
Examination	**Look, listen, feel** • Airway • Breathing and oxygenation • Circulation • Level of consciousness	**Structured examination of organ systems** • Respiratory system • Cardiovascular system • Abdomen and genitourinary tract • Central nervous and musculoskeletal systems • Endocrine and hematologic systems

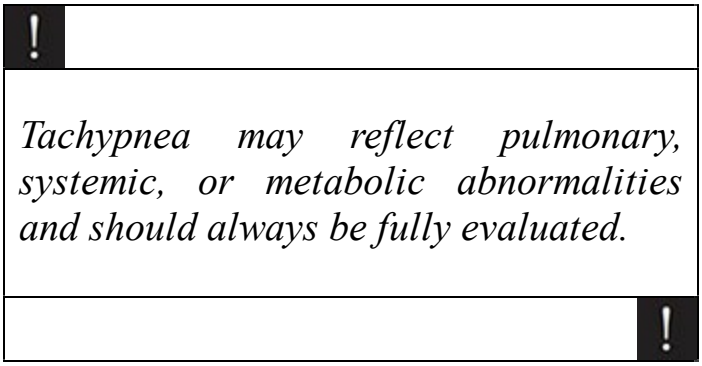
Chart Review: Documentation	**Essential physiology, vital signs** • Heart rate, rhythm • Blood pressure • Respiratory rate and pulse oximetry • Level of consciousness	**Case records and note keeping** • Examine medical records, if available • Formulate specific diagnosis or differential diagnosis • Document current events
Investigations	• Arterial blood gas analysis (can obtain venous blood gas if arterial access not possible) • Blood glucose	• Laboratory blood tests • Radiology • Electrocardiography • Microbiology
Treatment	**Proceeds in parallel** • Ensure adequate airway and oxygen • Provide intravenous access ± fluids • Assess response to immediate resuscitation • CALL FOR ASSISTANCE FROM AN EXPERIENCED COLLEAGUE	**Refine treatment, assess responses, review trends** • Provide support for specific organ systems as required • Choose most appropriate hospital site for care • Obtain specialist advice and assistance

A complete history includes the present complaint, treatment history, hospital course to the present (if applicable), past illnesses, past operative procedures, current medications, and any medication allergies. A social history, including alcohol, tobacco, or illicit drug use, and a family history, including the degree of physical, emotional, and psychosocial independence, are essential and often overlooked. The history of the present complaint must include a brief review of systems that should be replicated in the examination that follows.

Critical illness is often associated with inadequate cardiac output, respiratory compromise, and a depressed level of consciousness. Specific symptoms will typically be associated with the underlying condition. Patients may complain of nonspecific symptoms such as malaise, fever, lethargy, anorexia, or thirst. Organ-specific symptoms may direct attention to the respiratory, cardiovascular, or gastrointestinal systems. Distinguishing acute from chronic disease is important at this point, as chronic

conditions may be difficult to reverse and may act as rate-limiting factors during the recovery phase of critical illness.

B. Examination

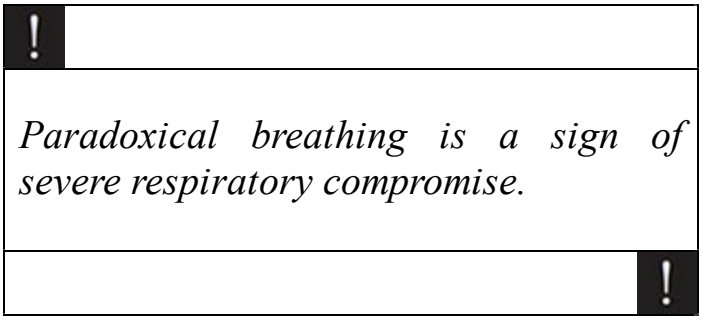


Look, listen, and feel. The patient must be fully exposed for a complete examination. The initial examination must be brief, directed, and concentrated on the basic elements of airway, breathing, circulation, and level of consciousness. As the treatment proceeds, a more detailed secondary survey should be conducted to refine the preliminary diagnosis and assess the response to the initial treatment. A full examination must be performed at some point and will be guided by the history and other findings. *Ongoing deterioration or development of new symptoms warrants repetition of the primary survey followed by a detailed secondary survey.*

Remember the ABCs of resuscitation: airway, breathing, and circulation. The airway and respiratory system should be assessed first, as summarized in **Table 1-2**. Observe the patient's mouth, chest, and abdomen. There may be obvious signs suggesting airway obstruction as vomitus, blood, or a foreign body. The patient's respiratory rate, pattern of breathing, and use of accessory respiratory muscles will help to confirm and assess the severity of respiratory distress or airway obstruction (**Chapter 2**). *Tachypnea is the single most important indicator of critical illness*. Therefore, the respiratory rate must be accurately measured and documented. Although tachypnea may result from pain or anxiety, it may also indicate pulmonary disease, severe metabolic abnormalities, or infection. Look for cyanosis, paradoxical breathing, equality and depth of respiration, use of accessory muscles, and tracheal tug. An increase in the depth of respiration (Kussmaul breathing) may indicate severe metabolic acidosis. Periodic breathing with apnea or hypopnea (Cheyne-Stokes respiration) usually indicates severe brainstem injury or cardiac dysfunction. Ataxic breathing (Biot respiration) indicates severe neuronal damage, which is associated with poor prognosis. Agitation and confusion may result from hypoxemia, whereas hypercapnia will usually depress the level of consciousness. Low oxygen saturation can be detected with pulse oximetry, but this

assessment may be unreliable if the patient is hypovolemic, hypotensive, or hypothermic. Noisy breathing (eg, grunting, stridor, wheezing, gurgling) may indicate partial airway obstruction, whereas complete airway obstruction will result in silence.

Table 1-2	Assessment of Airway and Breathing
	Airway
Causes of Obstruction	Direct trauma, blood, vomitus, foreign body, central nervous system depression (with soft tissue or tongue blocking airway), infection, inflammation, laryngospasm
LOOK for	Cyanosis, altered respiratory pattern and rate, use of accessory respiratory muscles, tracheal tug, paradoxical breathing, altered level of consciousness
LISTEN for	Noisy breathing (grunting, stridor, wheezing, gurgling); silence indicates complete obstruction
FEEL for	Decreased or absent airflow
	Breathing
Causes of Inadequate Breathing or Oxygenation	
Depressed respiratory drive	Central nervous system
Decreased respiratory effort	Muscle weakness, nerve/spinal cord damage, chest wall abnormalities, pain
Pulmonary disorders	Pneumothorax, hemothorax, aspiration, chronic obstructive pulmonary disease, asthma, pulmonary embolus, lung contusion, acute lung injury, acute respiratory distress syndrome, pulmonary edema, rib fracture, flail chest
LOOK for	Cyanosis, altered level of consciousness, tracheal tug, use of accessory respiratory muscles, altered respiratory pattern, altered respiratory rate, equality and depth of breaths, oxygen saturation
LISTEN for	Dyspnea, inability to talk, noisy breathing, dullness to percussion, auscultation of breath sounds
FEEL for	Symmetry and extent of chest movements, position of trachea, crepitus, abdominal distension



Inadequate circulation may result from primary abnormalities of the cardiovascular

system or secondary abnormalities caused by metabolic disturbances, sepsis, hypoxia, or drugs (**Table 1-3**). *A decrease in the blood pressure may be a late sign of cardiovascular disturbance signaling failure of the compensatory mechanisms*. Central and peripheral pulses should be assessed for rate, regularity, volume, and symmetry. Capillary or nail-bed refill exam may aid in detecting hypovolemia if delayed.

Table 1-3	Assessment of Circulation
Causes of Circulatory Inadequacy	
Primary — directly involving the heart	Ischemia, arrhythmias, valvular disorders, cardiomyopathy, pericardial tamponade
Secondary — pathology originating elsewhere	Drugs, hypoxia, electrolyte disturbances, dehydration, sepsis, acute blood loss, anemia
LOOK for	Reduced peripheral perfusion (pallor) and delayed capillary refill, hemorrhage (obvious or concealed), altered level of consciousness, dyspnea, decreased urine output, jugular venous distension
LISTEN for	Additional or altered heart sounds, carotid bruits
FEEL for	Precordial cardiac pulsation, central and peripheral pulses (assessing rate, quality, regularity, symmetry), cool extremities

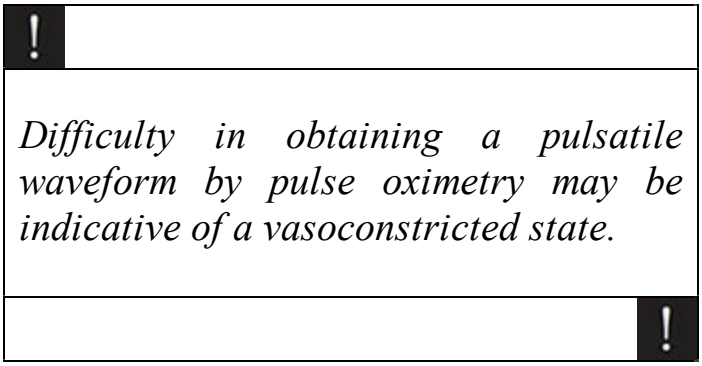
Patients with hypovolemia or low cardiac output will have weak and thready peripheral pulses. A bounding pulse suggests hyperdynamic circulation, and an irregular rhythm usually signifies atrial fibrillation. A ventricular premature beat is often immediately followed by a compensatory pause, and the subsequent beat often has a larger pulse volume. Pulsus paradoxus is seen as a greater than 10 mm Hg decrease in the systolic blood pressure with deep inspiration; it can occur with profound hypovolemia, constrictive pericarditis, cardiac tamponade, asthma, and chronic obstructive pulmonary disease. The location and character of the left ventricular impulse may suggest left ventricular hypertrophy, congestive heart failure, cardiac enlargement, severe mitral regurgitation, or severe aortic regurgitation. The turbulent flow of blood through a stenotic heart valve or a septal defect may produce a palpable thrill.

In addition to the ABCs, a quick external examination should look for pallor, cyanosis, diaphoresis, jaundice, erythema, or flushing. The skin may be moist or dry; appear thin, edematous, or bruised; or demonstrate a rash (ie, petechiae, hives). Fingernails may be clubbed or show splinter hemorrhages. The eyes might reveal abnormal pupils or jaundice. The conjunctiva may be pale, indicating an anemia. The patient may be alert, agitated, somnolent, asleep, or obtunded.

Palpation of the abdomen is an essential part of the examination of the critically ill

patient. Areas of abdominal tenderness and palpable masses must be identified. The size of the liver and spleen must be noted as well as any associated tenderness. It is important to assess the abdomen for rigidity, distension, fluid wave, or rebound tenderness. Auscultation may reveal a vascular bruit or the absence of bowel sounds. Intrauterine or ectopic pregnancy must be considered in all women of childbearing age. The flanks and back should be examined, if possible.

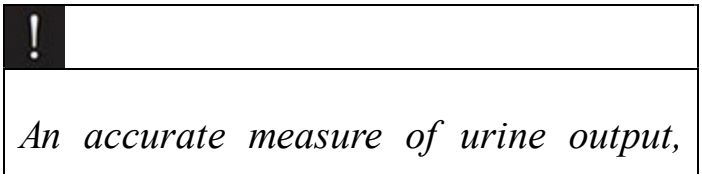
The Glasgow Coma Scale score should be recorded during the initial assessment of central nervous system function and limb movement (**Chapter 8**). Pupillary size and reaction should be documented, and a more detailed assessment of central and peripheral sensory and motor functions should be undertaken when time permits.



Difficulty in obtaining a pulsatile waveform by pulse oximetry may be indicative of a vasoconstricted state.

C. Chart Review and Documentation

Critically ill patients have abnormal physiology that must be documented and tracked. Physiological monitoring provides parameters that are useful only when they are accurate and interpreted by trained personnel (**Chapter 6**). The values and trends of these data provide key information for the assessment of the patient's status and guidance for treatment. Data must be charted frequently and correctly to ensure good patient care. Particular attention must be paid to the accuracy and reliability of the data. For example, a true and reproducible central venous pressure measurement depends upon patient position, equipment calibration, and proper zeroing of the instruments, as well as on heart rate and valvular function. The source of the data should also be noted. Is the recorded temperature a rectal measurement or an oral measurement? Was the blood pressure measured with a manual cuff or with a pressure transducer in an arterial line? The medication record is an invaluable source of information about prescribed and administered drugs.



An accurate measure of urine output,

usually with an indwelling catheter, is essential in critically ill patients.

Routine monitoring and charting should include heart rate, heart rhythm, respiratory rate, blood pressure, core temperature, fluid balance, and Glasgow Coma Scale score. The fluid balance should include loss from all tubes and drains. The inspired oxygen concentration should be recorded for any patient receiving oxygen, and oxygen saturation should be charted if measured with pulse oximetry. Patients in the ICU setting may have central venous catheters or continuous cardiac output catheters in place. These catheters can measure central venous pressure, various cardiac pressures, stroke volume variations, cardiac output, and mixed venous saturation. These complex monitoring devices require specific operational expertise. Likewise, the data must be interpreted by someone with clinical experience and expertise in critical care.

D. Investigations

Additional investigative tests should be based on the patient's history and physical examination as well as on previous test results. Standard biochemistry, hematology, microbiology, and radiology tests should be performed as indicated. *The presence of a metabolic acidosis is one of the most important indicators of critical illness*. In the evaluation of electrolyte results, decreasing total serum carbon dioxide and/or an increased anion gap are evidence of metabolic acidosis. An arterial blood gas analysis is one of the most useful tests in an acutely ill patient, providing information about blood pH, arterial oxygen tension, and arterial carbon dioxide tension. Additional tests, such as lactate, blood glucose, serum electrolytes, and renal function, can often be obtained from the same blood sample. The presence of lactic acidosis following cardiorespiratory resuscitation can be an ominous sign that should be closely monitored.

IV. TRANSLATING INFORMATION INTO EFFECTIVE ACTION

The framework in **Table 1-1** lays out a course of action based on first ensuring physiological stability and then proceeding to treatment of the underlying cause. The basic principles are summarized as the ABCs of resuscitating the severely ill patient: airway—ensuring a patent airway; breathing—providing supplemental oxygen and adequate ventilation; and circulation—restoring circulating volume. These early interventions should proceed regardless of the situation, while the context of the clinical

presentation (ie, trauma, postoperative situation, presence of chronic illness, advanced age) directs attention to the differential diagnosis and potential treatments. The clinical history, physical examination, and laboratory tests should aid in clarifying the diagnosis and determining the patient's degree of physiological reserve. Because the typical features of critical illness may be more effectively disguised in young and previously healthy patients than in the elderly or chronically ill, an acute deterioration may seem to occur more abruptly in younger individuals. Thus, it is particularly important to assess trends in vital signs and physiological parameters as the patient undergoes treatment. These trends can help determine a patient's response and clarify the diagnosis.

More experienced help must be obtained if a patient's condition is deteriorating and there is uncertainty about the diagnosis or treatment. Transfer to the most appropriate site for care is influenced by local resources, but transfer to a high-dependency unit or ICU must be considered.

Key Points

Recognition And Assessment Of The Seriously Ill Patient

- Early identification of a patient at risk is essential to prevent or minimize critical illness.
- The clinical manifestations of impending critical illness are often nonspecific. Tachypnea and metabolic acidosis are two of the most important predictors of risk; they signal the need for more detailed monitoring and investigation.
- Resuscitation and physiological stabilization often precede a definitive diagnosis and treatment of the underlying cause.
- A detailed history is essential for making an accurate diagnosis, determining a patient's physiological reserve, and establishing a patient's treatment preferences.
- Frequent clinical and laboratory monitoring of a patient's response to treatment is essential.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Cooper DJ, Buist MD. Vitalness of vital signs, and medical emergency teams. *Med J Aust*. 2008;188:630-631.

2. Cretikkos MA, Bellomo R, Hillman K, et al. Respiratory rate: the neglected vital sign. *Med J Aust*. 2008;188:657-659.

3. Hillman KM, Bristow PJ, Chey T, et al. Duration of life-threatening antecedents prior to intensive care admission. *Intensive Care Med*. 2002;28:1629-1634.

4. Harrison GA, Jacques TC, Kilborn G, et al. The prevalence of recordings of the signs of critical conditions and emergency responses in hospital wards: the SOCCER study. *Resuscitation*. 2005;65:149-157.

5. Hodgetts TJ, Kenward G, Vlachonikolis IG, et al. The identification of risk factors for cardiac arrest and formulation of activation criteria to alert a medical emergency team. *Resuscitation*. 2002;54:125-131.

6. O'Grady NP, Barie PS, Bartlett JG, et al. Guidelines for evaluation of new fever in critically ill adult patients: 2008 update from the American College of Critical Care Medicine and Infectious Diseases Society of America. *Crit Care Med*. 2008;36:1330-1349.

7. National Institute for Health and Care Excellence (NICE) Guidelines. Acutely ill adults in hospital: recognising and responding to deterioration. Published July 2007. https://www.nice.org.uk/guidance/cg50. Accessed April 15, 2016.

AIRWAY MANAGEMENT

Objectives

- Recognize signs of a threatened airway.
- Describe manual techniques for establishing an airway and for mask ventilation.
- Explain proper application of airway adjuncts.
- Describe preparation for endotracheal intubation, including the recognition of a potentially difficult intubation.
- Describe alternative methods for establishing an airway when endotracheal intubation cannot be accomplished.

Case Study

A 65-year-old man was admitted from the emergency department for worsening shortness of breath. He has a history of diabetes, hypertension, and chronic kidney disease for which he receives hemodialysis three times each week. He has missed his last two sessions of dialysis due to a gastrointestinal illness. You are called because the patient's oxygen saturation is 86% on 100% non-rebreather mask. He is using his accessory muscles to breathe and has visible nasal flaring. A portable chest radiograph shows pulmonary edema with small bilateral pleural effusions. An initial point-of-care arterial blood gas results yield a pH of 7.18, $Paco_2$ 21 mm Hg, and Pao_2 54 mm Hg. Lactic acid measured 5.2 mmol/L and potassium 6.9 mmol/L.

– Should this patient be intubated?

– If so, what drugs would be appropriate to use?

I. INTRODUCTION

This chapter focuses on the effective assessment and management of the airway. The primary goal is to maintain an open airway in order to facilitate adequate gas exchange, the *A* in the ABCs of resuscitation. Secondary goals include the preservation of cardiovascular stability and the prevention of aspiration of gastric contents during airway management. Endotracheal intubation will often be required, but establishing and maintaining a patent airway instead of, or prior to, intubation are equally important and often more difficult. Healthcare providers must be skilled in the manual support of an open airway and in providing the essential processes of oxygenation and ventilation. Securing an artificial airway via orotracheal or nasotracheal intubation, cricothyrotomy, or tracheostomy is an extension of, not a substitute for, the ability to maintain an open airway.

II. ASSESSMENT

Assessment of airway patency and spontaneous breathing effort is the crucial first step. The clinician must look, listen, and feel for diminished or absent air movement.

- Observe the patient's level of consciousness and determine if apnea is present. If respiratory efforts are absent and an immediate remedy is not available, proceed to manual support and assisted ventilation while preparing to establish an artificial airway.
- Identify injury to the airway or other conditions (eg, cervical spine injury) that will affect assessment and manipulation of the airway.
- Observe chest expansion. Ventilation may be adequate with minimal thoracic excursion, but respiratory muscle activity and even vigorous chest movement do not ensure that tidal volume is adequate.
- Observe for suprasternal, supraclavicular, or intercostal retractions; laryngeal displacement toward the chest during inspiration (a tracheal tug); or nasal flaring. These often represent respiratory distress with or without airway obstruction.
- Auscultate over the neck and chest for breath sounds. Complete airway obstruction is likely when chest movement is visible but breath sounds are absent. Airway narrowing due to soft tissue, liquid, or a foreign body in the airway may be associated with snoring, stridor, gurgling, or noisy breathing.

Absence of chest movement suggests apnea.

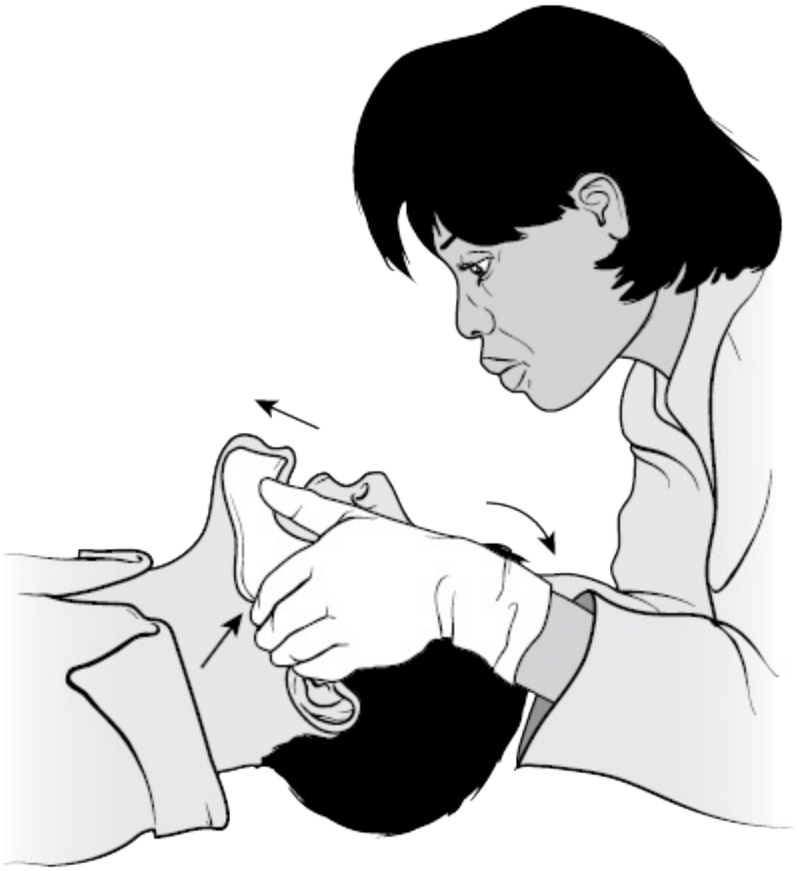
III. MANUAL METHODS TO ESTABLISH AN AIRWAY

Initial interventions to ensure a patent airway in a spontaneously breathing patient with no possible injury to the cervical spine include the following maneuvers (**Figure 2-1**):

1. Slight neck extension
2. Elevation of the mandible (jaw thrust maneuver)
3. Opening of the mouth

If a cervical spine injury is suspected, neck extension should not be done. After the cervical spine is immobilized, manual elevation of the mandible and opening of the mouth are performed.

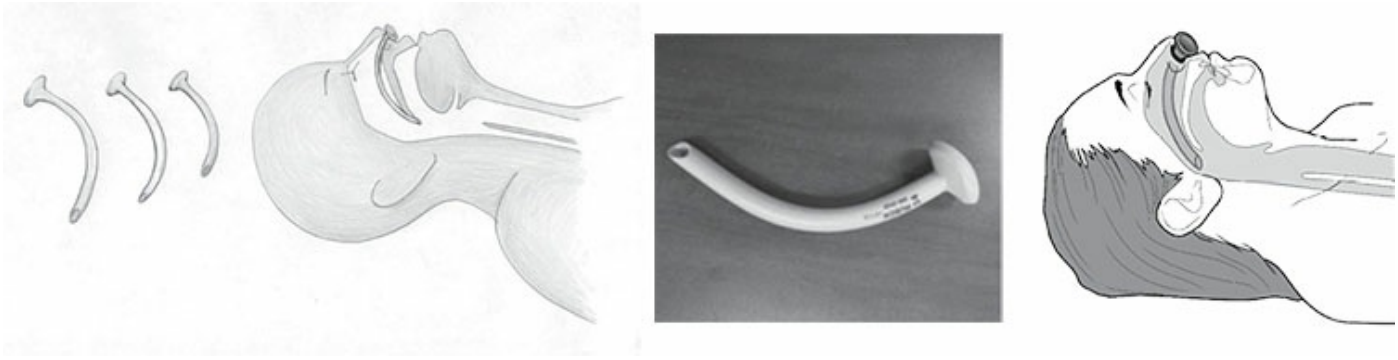
Figure 2-1. Establishing an Open Airway



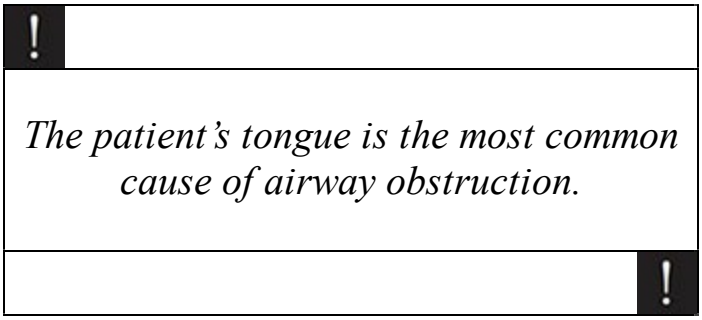
The operator extends the neck and maintains extension with his/her hands on both sides of the mandible. The mandible is elevated with the fingers of both hands to lift the base of the tongue, and the thumbs or forefingers are used to open the mouth.

Airway adjuncts such as properly sized oropharyngeal or nasopharyngeal airways may be useful. The oropharyngeal airway is not used if airway reflexes are intact, as gagging, laryngospasm, and emesis may be provoked. The diameter of a nasopharyngeal airway should be the largest that will easily pass through the nostril into the nasopharynx. Its length should extend to the nasopharynx, but it should not be so long as to obstruct gas flow through the mouth or touch the epiglottis. A nasopharyngeal airway is contraindicated in patients with suspected basilar skull fracture or coagulopathy. The correct length for each airway may be estimated by placing the device against the face in the correct anatomic position (**Figure 2-2**).

Figure 2-2. Nasopharyngeal Airway



During manual airway support, supplemental oxygen should be supplied with a device providing a high concentration of oxygen (100%) at a high flow rate. Such devices include a face mask or a bag-mask resuscitation unit, possibly with a positive end-expiratory pressure valve.



IV. MANUAL MASK VENTILATION

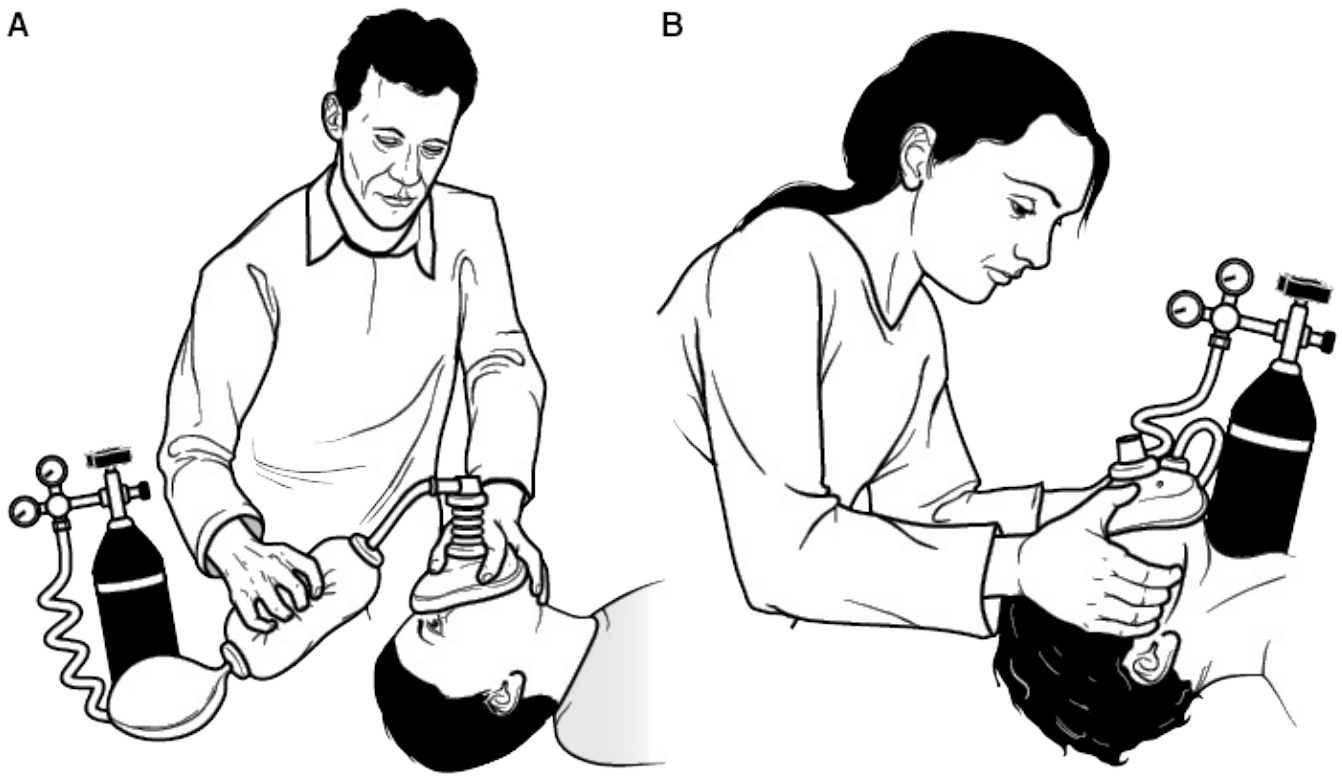
Manual assisted ventilation by means of a bag-mask resuscitation unit is indicated:

- if the patient is apneic.
- if spontaneous tidal volumes are determined to be inadequate based on physical examination or arterial blood gas analysis.
- to reduce the work of breathing by assisting spontaneous inspiration.
- if hypoxemia is associated with poor spontaneous ventilation.

Successful manual mask ventilation depends upon: (1) maintaining an open airway, (2) establishing a seal between the patient's face and the mask, and (3) delivering an adequate minute ventilation from the resuscitation bag to distal lung units. The first two elements are achieved through the correct placement of the mask over the patient's nose and mouth (**Figure 2-3**) and establishment of an open airway, as previously described. It is useful to have masks of different sizes available in the event that the initial selection

does not achieve a good seal with the face.

Figure 2-3. Application of Face Masks



Single-handed (**A**) and two-handed (**B**) techniques for placement of a face mask.

A. When No Cervical Spine Injury is Suspected

1. If needed and tolerated by the patient, an oropharyngeal or nasopharyngeal airway may be placed to maintain a patent airway. A small pad or folded towel may be positioned under the occiput.
2. The operator stands above and behind the head of the supine patient. The height of the bed should be quickly adjusted for the comfort of the operator.
3. The base of the mask is first placed into the skin crease between the lower lip and the chin, and the mouth is gently opened.
4. The apex of the mask is placed over the nose, using care to avoid pressure on the eyes.
5. As most operators are right-handed, the mask is stabilized on the face with the left hand by holding the superior aspect of the mask apex between the thumb and first

finger, adjacent to its connection to the bag. This allows gentle downward pressure on the mask over the face.

6. The fifth, fourth, and perhaps third fingers of the left hand are then placed along the left side of the mandible. It is helpful to gently encircle the left side of the mask with the soft tissues of that cheek to reinforce the seal along that edge. This further secures the mask to the patient's face while allowing the mandible to be partially elevated.

7. The operator gently rotates the left wrist to cause slight neck extension and contracts the fingers around the mandible to raise it slightly. The composite motions of the left hand, therefore, produce slight neck extension, mandibular elevation, and gentle downward pressure on the face mask.

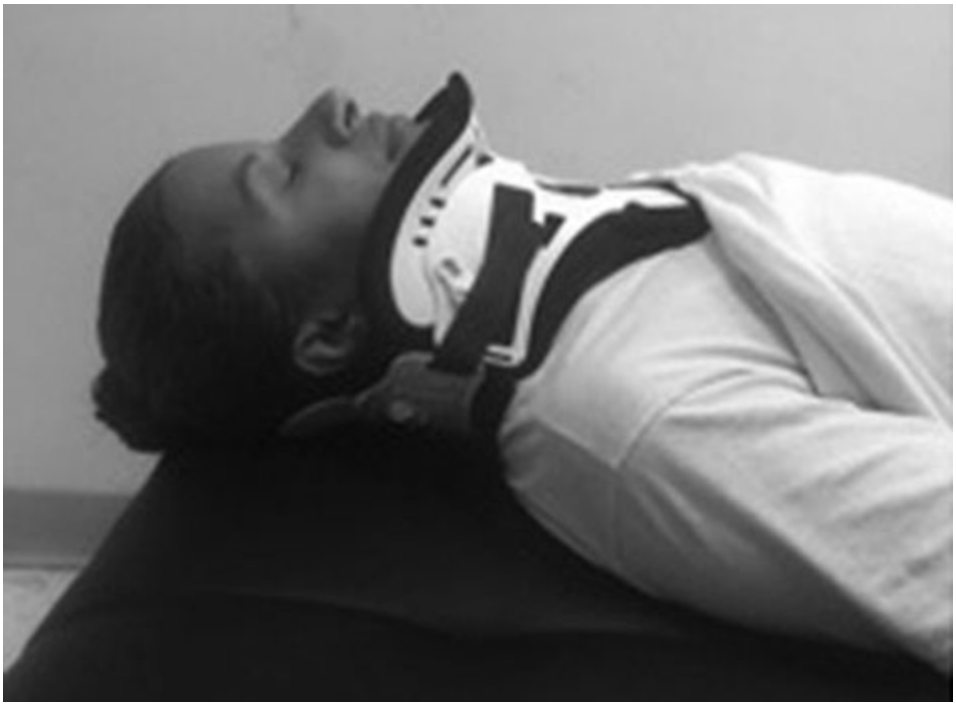
B. When a Cervical Spine Injury is Suspected

1. The operator stands in the same position, and an oropharyngeal or nasopharyngeal airway is inserted, if possible.

2. Successful manual ventilation occasionally can be accomplished while the neck is stabilized in a cervical collar (**Figure 2-4**). Most often, however, an assistant is required to stand to the side, facing the patient. The anterior portion of the collar is removed, and the assistant places one hand or arm along each side of the neck to limit movement of the neck during manipulation of the airway. Linear traction is not applied.

3. The operator then proceeds with the steps described above, *except the left wrist is not rotated to produce neck extension*. Alternatively, the operator may choose the two-handed method for mask placement, which further assures that no neck movement occurs. This method is discussed below.

Figure 2-4. Cervical Stabilization



C. Alternative Two-Handed Method to Ensure Airway Patency and Mask Application

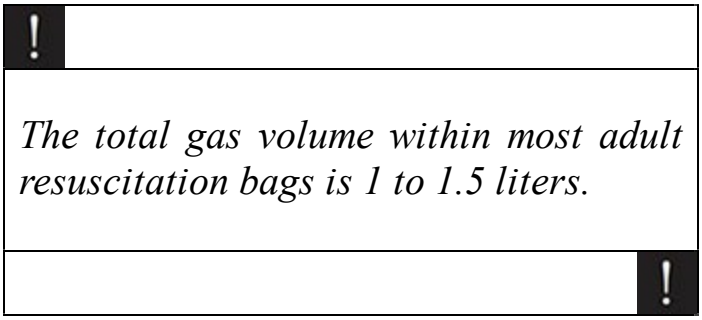
The alternative two-handed method is useful if the patient has a large face or a beard, after neck injury, or in any other situation when a mask seal is difficult to secure.

1. The operator stands at the head of the bed as before, and adjunctive airway devices are used as previously suggested.
2. The base and apex of the mask are placed in the manner previously described.
3. The operator places the third, fourth, and fifth fingers of both hands along the mandible on each side of the face while the thumbs rest over the apex of the mask and first fingers rest over the base of the mask.
4. Soft tissues of the cheek are brought upward along the side edges of the mask and held in place by each hand to reinforce the mask's seal.
5. In the absence of possible cervical spine injury, the neck is slightly extended as the operator gently elevates the mandible from both sides and provides gentle pressure on the mask over the face.
6. An assistant provides ventilation, as needed, by compressing the resuscitation bag.

D. Compression of the Resuscitation Bag to Provide Assisted Manual Mask

Ventilation

The goal of manual mask ventilation is to provide adequate minute ventilation, the product of the tidal volume delivered during each resuscitation bag compression and the number of compressions per minute. Overzealous resuscitation bag compressions at a rapid rate may produce dangerous hyperventilation and respiratory alkalemia, as well as gastric distension.



1. If a single-handed method of mask placement is used, the resuscitation bag is compressed over 1 second by the operator's right hand.

2. The delivered tidal volume must be estimated from the observed chest expansion and auscultated breath sounds.

3. During bag compression, the operator should listen carefully for any gas leaks around the mask. When a good seal is achieved, the feel of the bag during lung inflation reflects some resistance caused by the normal airway anatomy. If gas is moving from the bag too easily, a leak is likely to be present.

4. If the patient is apneic but has a pulse, one-handed bag compressions should be delivered 10 to 12 times per minute. If spontaneous breathing is present, bag compression should be synchronized with the patient's inspiratory efforts. If the patient is breathing easily and inhaling adequate tidal volumes frequently enough to produce sufficient minute ventilation, the bag need not be compressed at all.

5. Oxygen (100%) is delivered to the resuscitation bag, usually at a flow rate of 15 L/min.

6. If the mask-to-face seal is not adequate and a leak is detected, the operator should consider the following interventions:
   - Reposition the mask and hands.
   - Adjust the inflation of the facial cushion of the face mask, if possible, to improve the seal or change to a larger or smaller mask.

- Apply slightly more downward pressure to the face or displace the mandible in an upward fashion, provided cervical spine manipulation is not contraindicated.
- Convert to the two-handed technique described earlier.
- Reposition any orogastric or nasogastric tube to another part of the mask. Leaks are common when a tube is present, but rarely will it need to be removed.
- Consider compensating for a small leak by increasing the frequency of bag compressions or the volume of gas delivered in each compression.
- If the resuscitation bag has a pressure-relief (pop-off) valve designed to prevent transmission of high pressures to the lungs, adjust the pop-off valve to ensure adequate tidal volumes in patients with stiff lungs or high airway resistance.

Manual assisted ventilation should be continued in preparation for intubation or until the cause of inadequate ventilation is reversed. An assistant should prepare medications and equipment for intubation while the primary operator maintains ventilation. Pulse oximetry and cardiac monitoring are valuable adjuncts throughout assisted ventilation. The patient should be evaluated continuously for evidence of cyanosis, although this is a late finding in the setting of hypoxemia.

The SOAP ME mnemonic is helpful in preparation for airway management (**Table 2-1**).

Table 2-1 SOAP ME: Mnemonic for Preparation for Airway Management

1. **S**uction
    a. Use a suction device (Yankauer or catheter) to clear secretions, as needed.
    b. Check device and tubing for adequate suction strength.
2. **O**xygen
    a. Assure oxygen is connected and functioning.
    b. Prepare a bag-valve-mask device with a PEEP valve.
    c. Continue high flow supplemental oxygen by nasal cannula or face mask.
3. **A**irways
    a. Prepare appropriately sized cuffed endotracheal tube(s) with stylet. Consider size 7-7.5 for females, and size 7.5-8 for males. Check cuff for leaks.
    b. Consider airway adjuncts.
        i. Oropharyngeal and/or nasopharyngeal airways
        ii. Laryngeal mask airways
        iii. Esophageal-tracheal double-lumen airway device

4. **P**osition
    a. Adjust the bed height for airway operator's comfort.
    b. Place patient in sniffing position. Align the external auditory canal with the sternal notch.
    c. Consider elevating the back and shoulders of obese patients.
5. **M**onitoring and Medications
    a. Continual monitoring of vital signs, including oximetry and end-tidal CO_2
    b. Consider induction drugs (consider rapid sequence induction) **[Table 2.2]**.
        i. Hypnotic
        ii. Neuromuscular blocking agent
        iii. Postintubation sedation and analgesia
6. **E**quipment
    a. Laryngoscope(s) with curved and/or straight blades (MAC 3,4; Miller 2,3)
    b. Optical or video laryngoscope (with appropriate stylets)
    c. Bougie and/or airway exchange catheter
    d. End-tidal CO_2 detector, if continual end-tidal CO_2 monitoring not available
    e. Endotracheal tube fastener or tape to secure endotracheal tube

Adapted from: SOAP ME Mnemonic. University of Maryland Department of Emergency Medicine Educational Pearls. https://umem.org/educational_pearls/2577. Accessed September 1, 2015.
Abbreviation: PEEP, positive end-expiratory pressure

E. Cricoid Pressure

Cricoid pressure (Sellick maneuver) is the application of downward (posterior) pressure on the anterior neck overlying the cricoid cartilage, with an intended effect of physical occlusion of the esophagus. Cricoid pressure has been recommended for use during mask ventilation and intubation of patients who lack protective airway reflexes and during rapid sequence intubation. New guidelines no longer recommend cricoid pressure, except as a means of positioning the glottis for better visualization during laryngoscopy. It does not reduce risk of aspiration as previously thought. Proper application of cricoid pressure may improve vocal cord visualization. Excess pressure can compress the trachea and hypopharynx, compromise mask ventilation, and increase the difficulty of endotracheal intubation. Guidelines for managing the difficult airway, whether identified or unrecognized, are presented in **Figure 2-5**.

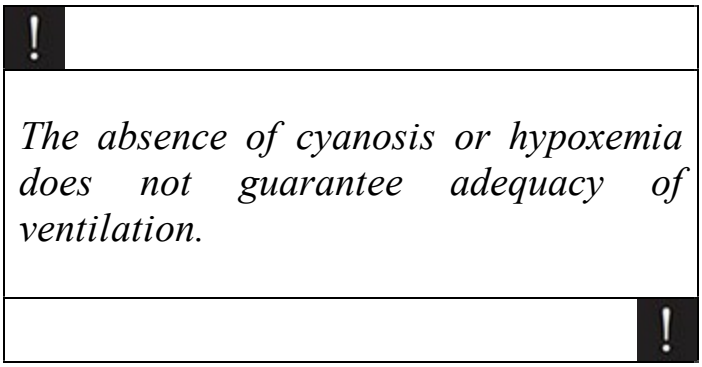
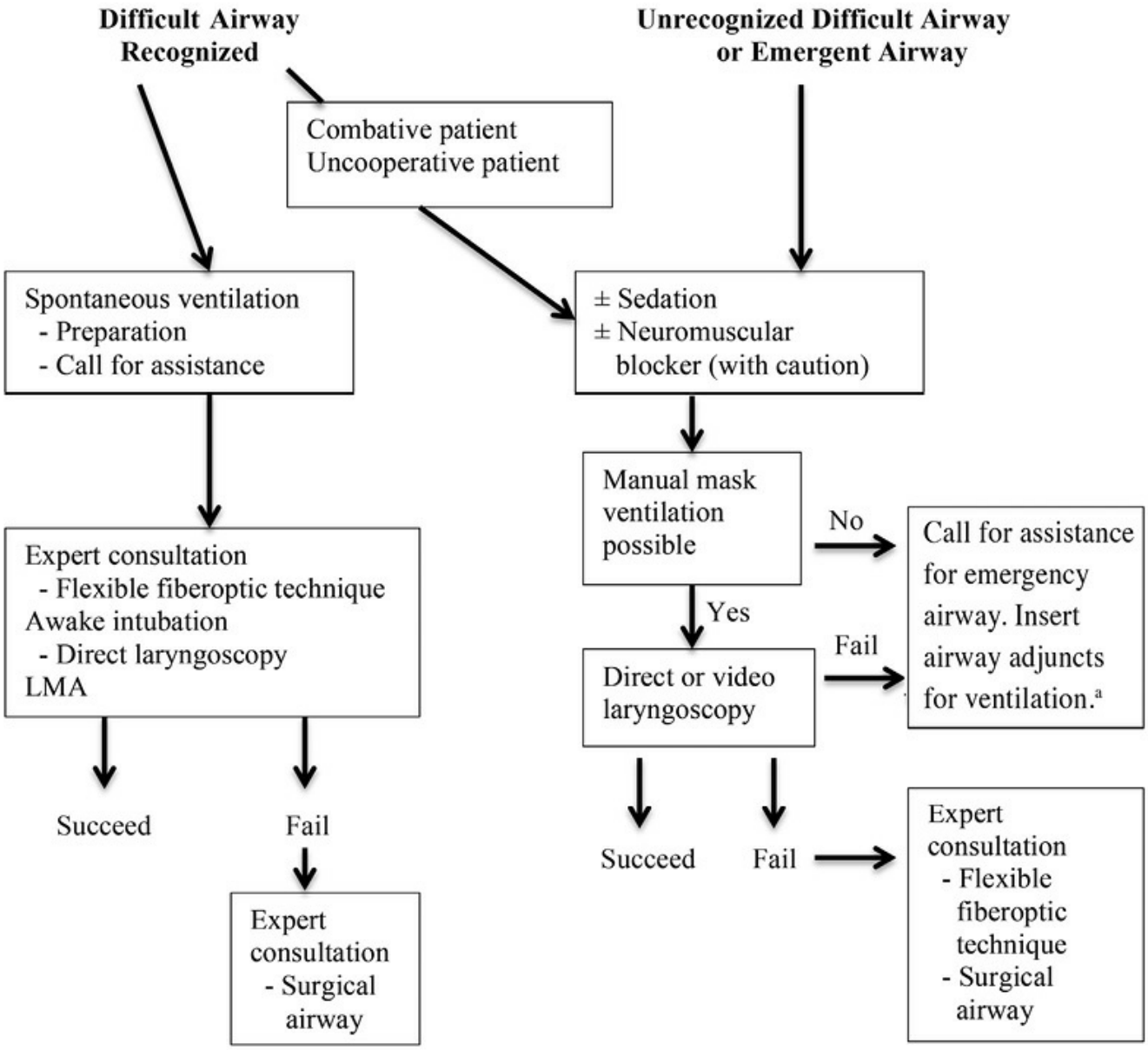


Figure 2-5. Management of the Difficult Airway



Abbreviations: LMA, laryngeal mask airway
[a]Airway adjuncts: LMA; esophageal-tracheal-double-lumen airway

V. AIRWAY ADJUNCTS

In approximately 5% of the general population, manual mask ventilation is difficult or impossible to achieve. Predictors of difficulty are the presence of a beard, absence of teeth, history consistent with obstructive sleep apnea, body mass index greater than 26 kg/m^2, and age older than 55 years. The presence of two predictors indicates a high

probability of difficulty in manual mask ventilation. Intubation via direct laryngoscopy is difficult in approximately 5% of the general population and impossible in 0.2% to 0.5%. A crisis situation occurs when manual mask ventilation and intubation are impossible. The laryngeal mask airway and esophageal-tracheal double-lumen airway device are useful adjuncts to provide an open airway and permit gas exchange in such situations. These devices are inserted blindly and their use may offer additional time after a failed intubation attempt. The choice of device depends on the operator's experience, equipment availability, and specific clinical circumstances.

A. Laryngeal Mask Airway

A laryngeal mask airway is a tube attached to a bowl-shaped cuff that fits in the pharynx behind the tongue. The standard type is reusable, but a single-use device is also available. A laryngeal mask airway may be used to ventilate the lungs when mask ventilation is difficult, provided that the patient does not have periglottal abnormalities. It may also serve as a conduit for intubation when a bronchoscope is used or as a rescue technique after failure to intubate. Less sedation is required with the laryngeal mask airway than with direct laryngoscopy because stimulation to the airway (eg, gagging, laryngospasm, sympathetic stimulation) in passing the device is only moderate. It is effective in ventilating patients ranging from neonates to adults, but it does not provide definitive airway protection. (For specific details regarding use of a laryngeal mask airway, see **Appendix 2**.)

B. Esophageal-Tracheal Double-Lumen Airway Device

Another tool for providing an emergency airway is a double-lumen device with two inflatable balloon cuffs. Although this item was designed primarily for blind intubation during cardiorespiratory arrest, it can provide ventilation if the distal cuffed portion of the tube device is inserted in the esophagus or trachea. Its use is contraindicated for patients with central airway obstruction, intact laryngeal or pharyngeal reflexes, known esophageal pathology, or ingestion of caustic substances. Adequate training is required to ensure appropriate use. (For information about inserting an esophageal-tracheal double-lumen airway device, see **Appendix 2**.)

VI. ENDOTRACHEAL INTUBATION

Direct laryngoscopy with orotracheal intubation is the principal method for tracheal intubation because of its speed, success rate, and availability of equipment. Blind

nasotracheal intubation may be useful for selected patients. The indications for tracheal intubation are summarized in **Table 2-2**, and the techniques for orotracheal and nasotracheal intubation are discussed and illustrated in **Appendix 3**.

Table 2-2	Indications for Tracheal Intubation

Airway protection

Relief of obstruction

Provision of mechanical ventilation and oxygen therapy

Respiratory failure

Shock

Hyperventilation for intracranial hypertension

Reduction of the work of breathing

Facilitation of suctioning/pulmonary toilet

In preparation for intubation, important issues include:

- Assessment of airway anatomy and function to estimate degree of difficulty for intubation (discussed later).
- Assurance of optimal ventilation and oxygenation. Preoxygenation with 100% oxygen, using a bag-mask resuscitation device, occurs during periods of apnea and before intubation attempts.
- Decompression of the stomach with an existing orogastric or nasogastric tube. However, the insertion of such tube to decompress the stomach prior to intubation is often counterproductive, as it may elicit emesis and promote passive reflux of gastric contents.
- Provision of appropriate analgesia, sedation, amnesia, and neuromuscular blockade as required for a safe procedure (discussed later).

Although emergent intubation leaves little time for evaluation and optimization of conditions, elective and urgent intubation allows for assessment of factors that promote safe airway management. The patient's clinical situation, intravascular volume status, hemodynamics, and airway evaluation (degree of difficulty) should be assessed as a plan for airway management is formulated. Airway evaluation includes assessment of physical characteristics that together determine if visualization of the vocal cords will

be difficult or impossible. This evaluation will suggest whether alternative techniques to direct laryngoscopy (eg, video laryngoscopy, awake intubation, flexible fiberoptic intubation, surgical airway) are likely to be necessary and whether a more experienced individual should be summoned immediately. Keep in mind that many of these physical characteristics also cause difficulty with mask ventilation and the ability to perform an emergent cricothyrotomy. These characteristics are easy to remember if they are considered in the same order as the steps used in oral intubation — that is, head position, mouth opening, displacement of the tongue and jaw, visualization, and insertion of endotracheal tube:

- *Neck mobility*. The presence of possible cervical spine injury, short neck, or limited neck mobility due to prior surgery or arthritis will restrict the ability to position adequately. If there is a possibility of cervical spine injury, neck extension should be avoided and an appropriately sized cervical collar should be placed for cervical motion restriction (**Figure 2-4**).

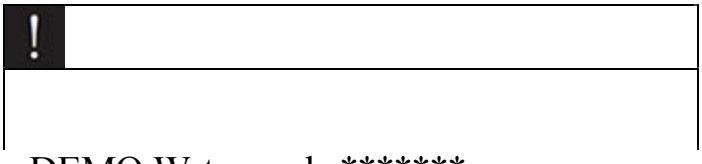
- *External face*. The patient should be examined for evidence of a small mandible or the presence of surgical scars, facial trauma, small nares, or nasal, oral, or pharyngeal bleeding.

- *Mouth*. Mouth opening may be limited due to temporomandibular joint disease or facial scarring. An opening of less than three finger breadths (approximately 6 cm) is associated with an increased risk of difficult intubation.

- *Tongue and pharynx*. Tongue size relative to the posterior pharynx provides an estimate of the amount of room in the pharynx to visualize glottic structures.

- *Jaw*. Thyromental distance is the distance in finger breadths between the anterior prominence of the thyroid cartilage (Adam's apple) and the tip of the mandible (chin), and is an estimate of the length of the mandible and the available space anterior to the larynx. A distance of less than three finger breadths (approximately 6 cm) indicates that the larynx may appear more anterior and be more difficult to visualize and enter during laryngoscopy. A more acute angulation of the stylet at the distal end of the endotracheal tube may be helpful (see above).

If one or a combination of these physical characteristics indicates the possibility of difficult intubation and if time allows, other options for obtaining a secure airway and summoning someone with additional airway expertise should be considered.



Failed intubation attempts can result in periglottic edema and create subsequent difficulty with mask ventilation, leading to a "can't intubate and can't ventilate" situation.

When difficulty in mask ventilation or intubation is anticipated, care is advised before suppressing spontaneous ventilation with neuromuscular blocking drugs or sedatives that cannot be reversed. Video laryngoscopy has shown to be an effective method of airway management as both a primary intubation technique and in management of the difficult airway. Options for safe airway management include the following, all of which preserve spontaneous ventilation:

- Awake intubation by direct or video laryngoscopy, or blind nasotracheal intubation
- Flexible fiberoptic intubation (expert consultation required)
- Awake tracheostomy (expert consultation required)

In the event that visualization of the glottis and mask ventilation are both impossible and there is no spontaneous ventilation, options include:

- Laryngeal mask airway or esophageal-tracheal double-lumen airway device
- Needle cricothyrotomy (expert consultation required)
- Surgical cricothyrotomy/tracheostomy (expert consultation required)
- Percutaneous tracheostomy (expert consultation required)

An algorithm for managing a potential or confirmed difficult airway is shown in **Figure 2-5**.

After tracheal intubation, significant alterations in hemodynamics should be anticipated. Hypertension and tachycardia may result from sympathetic stimulation, and some patients may require therapy with antihypertensive medications or sedatives. Hypotension is common, and decreased cardiac output, due to reduced venous return associated with positive pressure ventilation, can precipitate arrhythmias or cardiac arrest. The effects of sedative agents on the vasculature or myocardium, hypovolemia, and a possible postintubation pneumothorax may also contribute to hypotension. Other

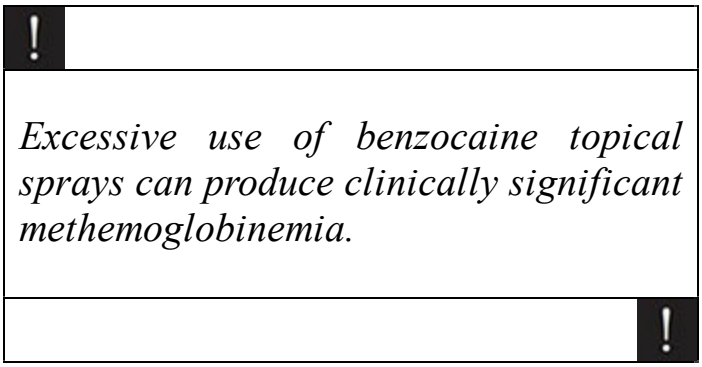
complications associated with positive pressure ventilation are discussed in **Chapter 5**.

VII. PHARMACOLOGIC PREPARATION FOR INTUBATION

During the process of airway management, both parasympathetic and sympathetic responses are common and may require control with proper pharmacologic therapy. The pharmacologic goal before intubation is to provide the patient with optimal analgesia/anesthesia, amnesia, and sedation without altering cardiopulmonary stability. At times, preservation of spontaneous ventilatory drive is necessary. The selection of particular methods or drugs depends upon the clinical circumstances and the patient's status, patient allergies, and the experience and preferences of the operator.

A. Analgesia/Anesthesia

- A variety of topical anesthetic sprays are available, or lidocaine may be delivered via an aerosol. Anatomic areas for special emphasis include the base of the tongue, directly on the posterior wall of the pharynx, and bilaterally in the tonsillar fossae. Care should be taken not to exceed 4 mg/kg of lidocaine (maximum dose 300 mg), as it is easily absorbed from the airway mucosa.
- Administration of nerve blocks and transcricoid membrane lidocaine requires special expertise outside the scope of this course.
- Some sedative agents also have analgesic properties; most do not.



B. Sedation/Amnesia

Rapid-acting, short-lived, and potentially reversible agents are preferred for sedation. No single agent has every desirable feature, and often more than one agent may be

considered to provide a balanced technique. The status of the patient's intravascular volume and cardiac function must be carefully considered during the selection of an agent and its dosage. Most may induce hypotension when heart failure or hypovolemia is present. Examples of commonly used medications are listed in **Table 2-3**. Be prepared to manage hypotension following induction with fluid boluses and/or vasopressors (**Chapters 5** and 7).

Table 2-3 Drugs Used to Facilitate Tracheal Intubation[a]

Agent	Dosing	Benefits	Cautions
Fentanyl	0.5-2 µg/kg IV bolus every several minutes titrated to analgesic effect	Rapid onset of action Short acting Reversible with naloxone	Chest wall rigidity with rapid administration Respiratory depression Does not inhibit patient awareness of procedure
Midazolam	0.1-0.3 mg/kg bolus titrated to sedative effect every several minutes	Provides amnesia Rapid onset of action Short acting Reversible with flumazenil	Additive respiratory depression when combined with narcotic Does not provide analgesia
Etomidate	0.1-0.3 mg/kg single IV bolus	Provides hypnosis *May* be preferred in head injury No adverse cardiovascular effects	May induce myoclonus, including mild trismus (consider premedication with 50 µg fentanyl) No reversal agent Transient adrenal suppression
Lidocaine	1-1.5 mg/kg IV bolus 2-3 minutes before laryngoscopy	Blunts hemodynamic and tracheal response to intubation May reduce elevations of intracranial pressure during laryngoscopy	Should not exceed 4 mg/kg total dose due to neurotoxicity (seizures)
Ketamine	1-4 mg/kg IV bolus	Rapid onset No adverse cardiovascular effects (except in severe congestive heart failure) Short acting	May increase intracranial pressure May result in hallucinations upon emergence Consider small dose of benzodiazepine (midazolam 0.5-1 mg IV) as an adjunct
Propofol	1-2 mg/kg IV bolus	Rapid onset Short acting Provides amnesia	Severe hypotension in volume-depleted patients Does not provide analgesia Respiratory depression

[a]The medications and doses listed are for induction in intubation in adult patients and are not intended for ongoing sedation or pain control.

C. Neuromuscular Blockers

Often, intubation can be safely and easily performed after topical anesthesia (ie, an awake intubation), or with sedation alone. Therefore, neuromuscular blockade is not always required before endotracheal intubation. Obviously, if the operator cannot intubate the patient after neuromuscular blockers have been given, effective manual mask ventilation must be continued while a more experienced person is sought, an alternative plan to secure the airway is developed, or the agent is metabolized with return of spontaneous ventilation. Hence, a short-acting agent is advantageous. The following are examples of neuromuscular blockers:

- Succinylcholine, 1 to 1.5 mg/kg intravenous bolus: rapid onset; shortest duration, which provides an element of safety; may cause muscle fasciculations because this agent depolarizes skeletal muscle; emesis may occur if abdominal muscle fasciculations are severe; contraindicated when ocular injury is present; relatively contraindicated when head injury or hyperkalemia is present (potassium release of 0.5-1 mmol/L will occur routinely, and massive potassium release may occur in burn and crush injury, upper motor neuron lesions, or primary muscle disease); may precipitate malignant hyperthermia. Effects are prolonged in patients with atypical cholinesterase or decreased pseudocholinesterase levels.
- Vecuronium, 0.1 to 0.3 mg/kg; rocuronium, 0.6 to 1 mg/kg; or cisatracurium, 0.1 to 0.2 mg/kg intravenous bolus: no fasciculations because these are nondepolarizing agents; slower onset of muscle paralysis; significantly longer duration of effects than with succinylcholine.

D. Rapid Sequence Intubation

Rapid sequence intubation is the simultaneous administration of a sedative agent and a neuromuscular blocker, designed to facilitate intubation and reduce the risk of gastric aspiration. It is the technique of choice when there is an increased risk of aspiration (eg, full stomach, pain, gastroesophageal reflux) and examination does not suggest a difficult intubation. Patients in whom intubation is likely to be difficult should not have rapid sequence intubation. The emergency methods described earlier will be necessary if the patient cannot be intubated and is impossible to ventilate, because the ability to ventilate via mask is not tested before administration of the neuromuscular blocker.

E. Intracranial Pressure

Intracranial pressure may rise during laryngoscopy and intubation, and this may be harmful in patients with preexisting intracranial hypertension. Intravenous lidocaine (1-1.5 mg/kg) has been shown to blunt this response and should be administered before laryngoscopy when intracranial pathology is suspected.

Key Points

Airway Management

- Assessment of the patient's level of consciousness, airway protective reflexes, respiratory drive, obstruction(s) to gas flow into the airway, and work of breathing will determine the steps necessary to ensure appropriate respiratory support.
- Every primary care provider must be skilled in manual methods to secure and maintain a patent airway.
- Manual assisted ventilation performed with a bag-mask resuscitation unit is a skill expected of every healthcare provider. The goal is to optimize oxygenation and CO_2 removal before, or in lieu of, intubation of the patient.
- Proper application of cricoid pressure may reduce the risk of gastric distension and passive aspiration.
- The laryngeal mask airway and esophageal-tracheal double-lumen airway device are useful airway adjuncts when expertise in intubation is lacking or intubation is unsuccessful.
- Before intubation, patient evaluation is necessary to assess the degree of difficulty and determine the appropriateness of analgesia, sedation, amnesia, and possible neuromuscular blockade.
- A plan for managing a potentially difficult intubation includes maintenance of spontaneous ventilation, video laryngoscopy, alternatives to endotracheal intubation, and requests for expert assistance. When manual mask ventilation is impossible after failed intubation, proper use of adjunct devices, cricothyrotomy, or percutaneous tracheostomy may be lifesaving.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. American Society of Anesthesiologists Task Force on Management of the Difficult Airway. Practice guidelines for management of the difficult airway: an updated report by the American Society of Anesthesiologists Task Force on Management of the Difficult Airway. *Anesthesiology*. 2013;118(2):251-270.

2. Barr J, Fraser GL, Puntillo K, et al. Clinical practice guidelines for the management of pain, agitation and delirium in adult patients in the intensive care unit. *Crit Care Med*. 2013;41(1):263-306.

3. Consilvio C, Kuschner WG, Lighthall GK. The pharmacology of airway management in critical care. *J Intensive Care Med*. 2012;27(5):298-305.

4. Danks RR, Danks B. Laryngeal mask airway: review of indications and use. *J Emerg Nurs*. 2004;30:30-35.

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6. El-Orbany M, Woehlck HJ. Difficult mask ventilation. *Anesth Analg*. 2009;109(6):1870-1880.

7. Ellis DY, Harris T, Zideman D. Cricoid pressure in emergency department rapid sequence tracheal intubations: a risk-benefit analysis. *Ann Emerg Med*. 2007;50(6):653-665.

8. Galvagno S, Restrepo R. Airway complications and management [video]. Society of Critical Care Medicine. Uploaded Oct 18, 2012. www.sccm.org/Education-Center/Clinical-Resources/Pages/Mechanical-Ventilation.aspx

9. Hurford WE. The video revolution: a new view of laryngoscopy. *Respir Care*. 2010;55(8): 1036-1045.

10. Mayglothling J, Duane TM, Gibbs M, et al. Emergency tracheal intubation immediately following traumatic injury: an Eastern Association for the Surgery of Trauma practice management guideline. *J Trauma Acute Care Surg*. 2012;73(5):S333-S340.

11. Stollings JL, Diedrich DA, Oyen LJ, et al. Rapid-sequence intubation: a review of the process and considerations when choosing medications. *Ann Pharmacother*. 2014;48(1):62-76.

12. Walz JM, Zayaruzny M, Heard SO. Airway management in critical illness. *Chest*. 2007;131:608-620.

13. Mehta M, Bhagat M, Song YB, et al. Intubation and airway monitoring. In: Rajaram SS, ed. *Critical Care Procedure Book*. Hauppauge, NY: Nova Publishers; 2015:89-99.

Suggested Website

1. Society of Critical Care Medicine. http://www.SCCM.org/Guidelines

CARDIOPULMONARY/CEREBRAL RESUSCITATION

Objectives

- Identify patients who are likely to benefit from cardiopulmonary resuscitation.
- Propose a process for delegating responsibilities during the resuscitative process.
- Discuss important treatment issues in cardiopulmonary arrest.
- Emphasize goals and interventions for brain protection and recovery, including use of therapeutic hypothermia.
- Review specific cardiopulmonary events that occur in critically ill, ventilated patients.

Case Study

A code blue (cardiac arrest) is called on the overhead paging system. You respond to the indicated room on a general floor to find a 42-year-old woman who is pulseless and apneic. A nurse is placing oxygen on the patient. Another nurse is attempting to place an IV line.

– What should be your immediate actions?

– What are the next steps if you are the team leader?

– What tasks are delegated to team members during the resuscitation?

I. INTRODUCTION

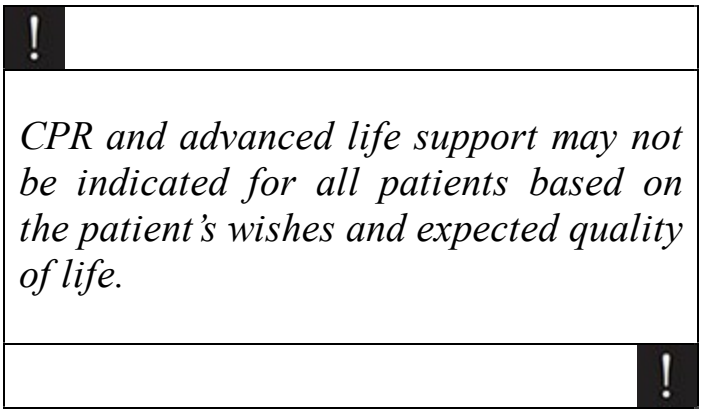
The immediate response to an in-hospital cardiac arrest is frequently the responsibility of primary care providers, hospitalists, nurses, house staff, and other members of the

healthcare team. The Society of Critical Care Medicine and the Fundamental Critical Care Support program recognize the valuable training provided by the American Heart Association's Basic Life Support (BLS), Advanced Cardiovascular Life Support (ACLS), and Pediatric Advanced Life Support (PALS) curricula. All healthcare practitioners are encouraged to successfully complete the appropriate courses.

II. ETHICAL ISSUES

A. Who Should Be Resuscitated?

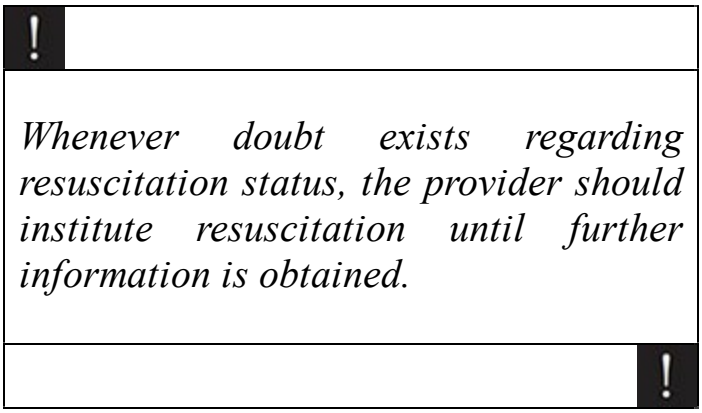
The purpose of cardiopulmonary resuscitation (CPR) and advanced life support is to reverse sudden, unexpected death resulting from reversible disease processes or iatrogenic complications. If possible, resuscitation status and any limitations should always be discussed with the patient, the patient's family, or the surrogate decision maker before a cardiac arrest event (**Chapter 15**). Resuscitation is unlikely to benefit patients experiencing a cardiac arrest despite maximal medical therapy for progressive cardiogenic or septic shock. Out-of-hospital arrest can carry a very high mortality rate in conjunction with prolonged CPR. Several other underlying conditions (eg, pneumonia, congestive heart failure, renal failure, and sepsis) make survival from cardiac arrest exceedingly unlikely but not unprecedented. No set of variables is sensitive enough to accurately predict a poor outcome.



B. Level of Therapeutic Support

CPR is instituted based on implied consent, without a physician's order. However, any limitation of resuscitation requires a physician's order. Do-not-attempt-resuscitation (DNAR/DNR) orders should be documented in the chart with a detailed explanation of

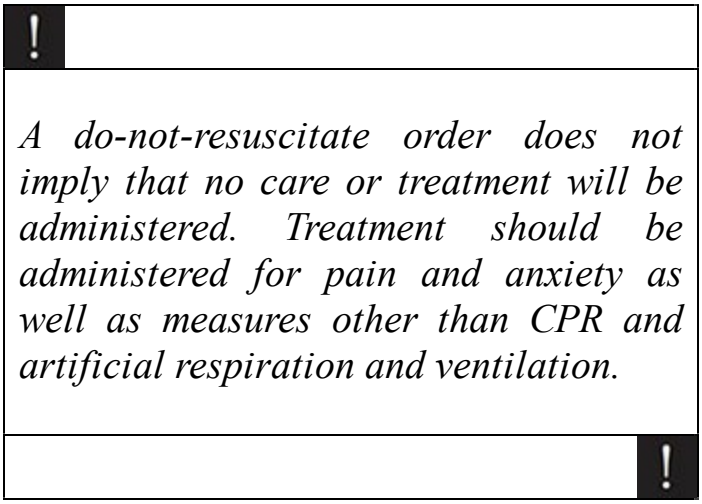
the rationale. Such orders *do not and should not* indicate that the patient is not to be treated. Patients and their families should not be abandoned emotionally because of such orders. "No resuscitation" does not mean "no care and no treatment." Individual resuscitative plans suited to a patient's particular wishes and condition should be clearly delineated in the chart by the attending physician. Pain and anxiety should be treated in all cases regardless of a patient's resuscitation status.



Whenever doubt exists regarding resuscitation status, the provider should institute resuscitation until further information is obtained.

C. Documentation

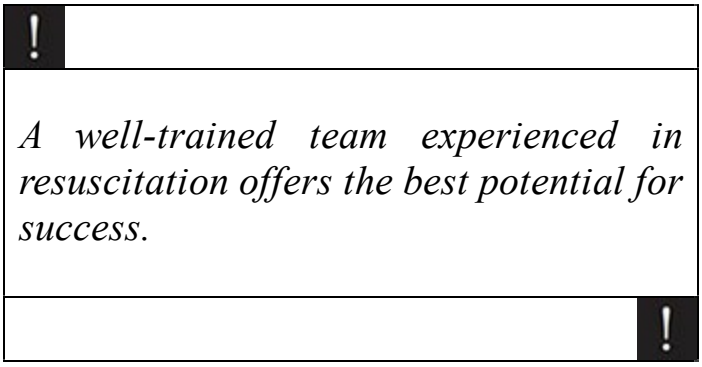
The intended level of therapeutic support should be documented in the patient's chart so that the medical and nursing staff knows exactly how to proceed should a cardiorespiratory arrest occur unexpectedly. A discussion of potential resuscitative measures should occur with all patients on admission regardless of the acuity of their clinical status. The staff should follow valid DNAR/DNR orders. Information about advance directives, living wills, durable powers of attorney, and related forms also should be documented and respected.



A do-not-resuscitate order does not imply that no care or treatment will be administered. Treatment should be administered for pain and anxiety as well as measures other than CPR and artificial respiration and ventilation.

III. PRIMARY RESPONSE

Responders will usually have resuscitation resources available for cardiorespiratory arrests that occur within the hospital. Often, however, the most important aspects of a successful resuscitation relate to the interactions, knowledge, and skills of the responders and the ability to delegate and accept responsibility for components of the resuscitation effort.



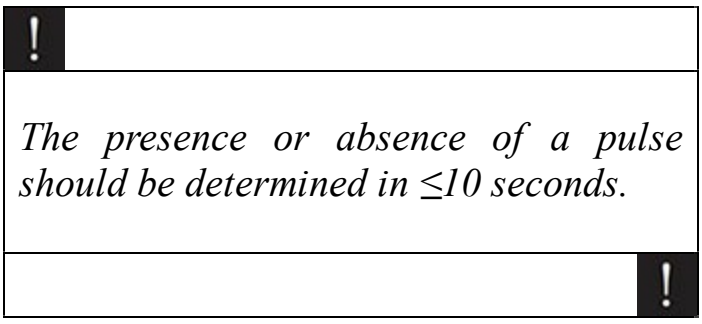
A. Assessment of the Immediate Situation

Has an appropriate individual assumed the leadership role?

- If so, how can you assist? Identify yourself and offer help. Be ready to accept a delegated role and to focus your efforts upon that role while remaining aware of other evolving resuscitation activities.
- You may be required to assume the leadership role until a more qualified individual or the designated team member arrives.

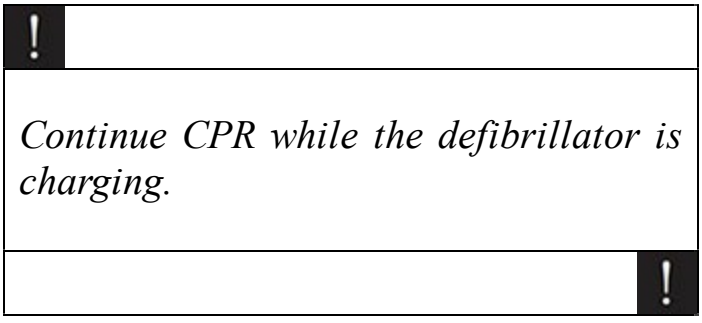
B. The Leader's Role

Proceed with primary assessment and intervention, and delegate appropriate activities to others.



1. Evaluation and Initial Cardiac Resuscitation

- Assess patient responsiveness.
- If the patient is unresponsive, assess the respiratory effort and pulses. If these are absent, activate your emergency response system, obtain an automated external defibrillator (AED) or monitor/defibrillator, and start chest compressions (CPR) immediately at a rate of at least 100/min, and at a depth of at least 2 inches (5 cm) in adults. *Push hard, push fast*. Healthcare providers should provide 2 breaths over 1 second each, with a ratio of compression to ventilation of 30:2, during each 2-minute cycle of CPR. The breaths should be of sufficient volume to see the chest rise and contain the maximum oxygen concentration available. Compressions-only CPR is acceptable for non-healthcare providers.
- Defibrillation should be initiated as soon as possible if monitoring (eg, quick-look paddles) indicates ventricular fibrillation or pulseless ventricular tachycardia. A single shock should be delivered at the energy level appropriate for the defibrillator (360 joules with a monophasic defibrillator or 200 joules with a biphasic defibrillator). Chest compressions should be resumed immediately after the shock is delivered without checking the pulse or rhythm. Rhythm analysis should usually occur after 2 minutes of compressions, but this sequence may be modified in the hospital setting with continuous electrocardiographic (ECG) monitoring.
- If intubated and connected to a mechanical ventilator, the patient must be disconnected and changed to manual bag-mask ventilation.



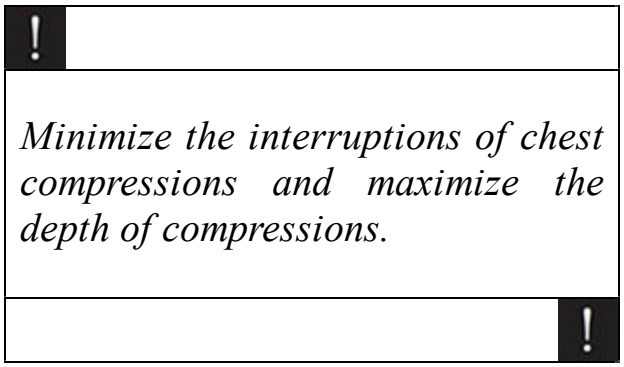
2. Delegation

- Delegate tasks to the most appropriate personnel available whenever possible. This allows the resuscitation leader to maintain an overall perspective, monitor cardiac rhythm, direct assessments and interventions, and prescribe medications. The leader may need to perform some of these tasks or reassign them if the primary designee is unsuccessful. Obviously, if the number of responders is not sufficient,

team members must establish priorities for performance. Delegated duties should include the following:

a. Manage the airway (**Chapter 2**). Establish a patent airway, provide manual bag-mask ventilation, utilize available airway adjuncts, and/or perform endotracheal intubation. Ventilations should not exceed the recommended 8 to 10 breaths/min to optimize coronary artery perfusion pressure by decreasing the percentage of time in positive intrathoracic pressure. Avoid hyperventilation.

b. Perform chest compressions. The resuscitation leader should designate a second person for relief and instruct the rescuers to exchange responsibilities every 2 minutes. Evidence shows that a compression rate of at least 100/min results in maximal blood flow for the patient. The ratio of compression to ventilation is 30:2 without an advanced airway in place, and the depth of compressions for adults is at least 2 inches (5 cm). *The chest should recoil completely between compressions*. If the patient has an advanced airway in place, compressions are continuous, and asynchronous ventilation is provided at a rate of 8 to 10 breaths/min. The person on relief should monitor the effectiveness of compressions by checking the carotid or femoral pulse. Chest compressions are interrupted only for shock delivery and rhythm checks once the airway is secured. Pulse checks are performed only if an organized rhythm is noted.



Minimize the interruptions of chest compressions and maximize the depth of compressions.

c. Attach ECG monitor/machine.

d. Obtain intravenous or intraosseous access. Peripheral venous access with a large catheter is preferred because it does not require interruption of chest compressions. The intraosseous route can be used as a temporary measure when other vascular sites are not immediately available in children or adults (**Chapter 4**).

e. Provide medications as requested (eg, to manage the code cart,

defibrillator/pacer).

f. Maintain record of resuscitation interventions and patient assessments.

g. Obtain medical record and/or provide pertinent patient information.

h. Notify the patient's personal attending physician of the cardiopulmonary event and obtain further guidance. Discuss the patient's status, medical history, existence of advance directives, and related topics.

i. Remove furniture, unnecessary equipment, and extra personnel from the resuscitation area.

j. Notify the patient's family of current events and provide emotional support. If family members are present at the bedside, allow them to remain and provide explanation of the procedures and emotional support. (Nurses and/or staff chaplains often assume this role.)

IV. CONTINUING RESUSCITATION

Once the primary response and assigned tasks have been successfully initiated, each team member continues an appropriate role as the resuscitation interventions are implemented.

- Critical laboratory data should be obtained to assist with decisions during the resuscitation and, perhaps, to reveal a cause for the cardiac arrest. Important data include levels of glucose and measures of arterial blood gases, potassium, ionized calcium, phosphorus, and magnesium. Suspected abnormalities or those documented in recent laboratory values may be treated empirically. Laboratory personnel should be notified of the ongoing resuscitation.

- During cardiopulmonary resuscitation events, many institutions use bedside ultrasound as a diagnostic tool to evaluate the patient's cardiac tamponade status, cardiac function, or return of circulation. This is done where bedside ultrasound is available.

- The patient's chart should be reviewed for history and any possible medication reaction that could lead to cardiac arrest, arrhythmia, or decreased ventilatory drive.

- It is appropriate to assume that the initial cardiopulmonary arrest would not have been announced if a DNAR/DNR or similar directive had been ordered by a

physician – but this should be confirmed as other patient information and data are obtained. *Whenever doubt exists about a patient's resuscitation status, full resuscitative measures should be initiated and continued until clarified with the patient's attending physician and/or family/surrogate.*

- The point at which family members are notified of the cardiopulmonary arrest will vary. If family is present, a team member should provide information periodically during the resuscitation. The presence of family during resuscitation should be carefully considered and planned for if this practice is accepted by the institution and the resuscitation team.

- Arrangements for patient transfer to an ICU should be considered. A transport cart, emergency drugs, external pacer, portable monitors, oxygen, and other crucial supplies should be available to facilitate immediate transfer as the patient stabilizes. The ICU will need to prepare, so additional patient needs (eg, presence of arterial or central lines and mechanical ventilation) should be communicated.

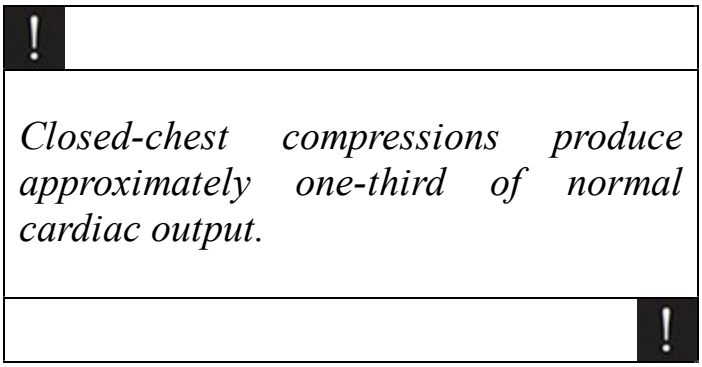
V. OTHER CONSIDERATIONS IN CARDIOPULMONARY/CEREBRAL RESUSCITATION

- The method that best produces blood flow to the coronary arteries, brain, and other organs during a cardiopulmonary arrest has not yet been determined. At present, closed-chest compressions remain the standard technique for circulatory support. Interposed abdominal compression CPR and active compression-decompression CPR (device not available in the United States) may be considered acceptable alternatives whenever personnel trained in the techniques are available. Use of mechanical chest compression devices is increasing in CPR. The invasive alternative of open-chest cardiac massage requires a team with special expertise and early institution for optimal outcome. Immediate cardiopulmonary bypass may be effective in improving the success of resuscitation but is not available in most hospitals.

- Early restoration of perfusion to the brain and other organs offers the best chance for recovery of function. Patients who are mildly hypothermic after cardiac arrest should not be actively warmed because warming increases oxygen demand and alters vascular tone. Targeted temperature management (32°C to 36°C [89.6°F to 98.6°F]) for at least 24 hours has been recommended to improve neurologic outcome and reduce mortality in comatose patients following initial resuscitation from and arrest (see Section VI). Febrile patients should be treated to reach a

normal temperature as soon as possible. Seizures must be aggressively treated to avoid further brain injury. Hyper- and hypoglycemia should be avoided because these conditions have been correlated with a worsened neurologic outcome. Other strategies to protect the brain during and after no-flow states and in conjunction with CPR are under investigation.

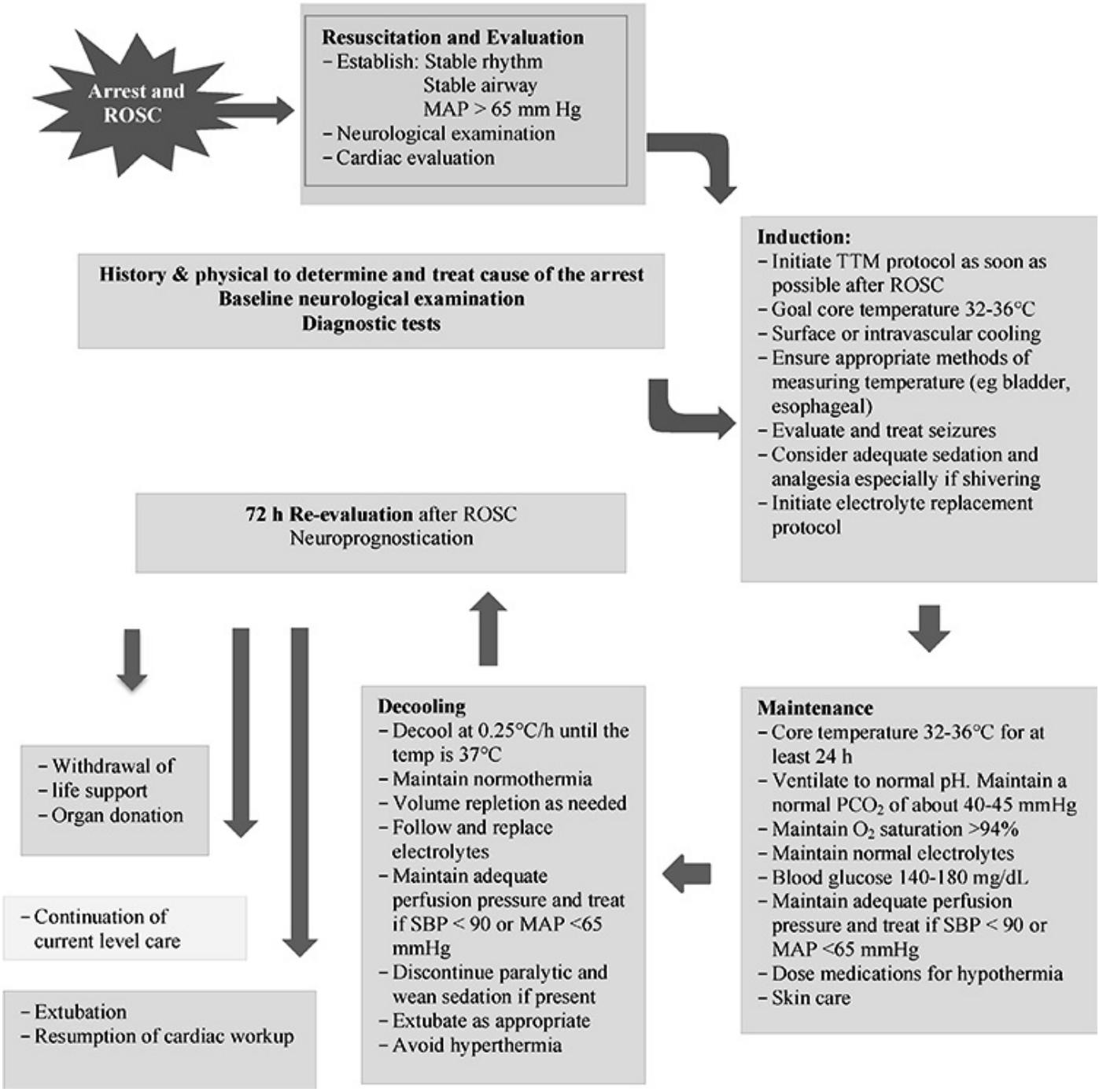
- Quantitative end-tidal CO_2 measurement with waveform display is recommended for the intra- and post-resuscitation management of cardiac arrest. Detection of or a rapid increase in end-tidal CO_2 is often the earliest indication of return of spontaneous circulation (ROSC). Normocapnia (P_{CO_2} 38-42 mm Hg) is the goal.



VI. TARGETED TEMPERATURE MANAGEMENT

Targeted temperature management (TTM), or therapeutic hypothermia, is a critical part of the cardiocerebral resuscitation process. Early restoration of perfusion to the brain and other organs offers the best chance for functional recovery. Avoidance of hyperthermia in the post-cardiac arrest period is essential. TTM as low as 32°C to 34°C (89.6°F to 96.8°F) core body temperature is recommended for patients with out-of-hospital or in-hospital cardiac arrest due to ventricular fibrillation or pulseless ventricular tachycardia who remain unconscious after ROSC (**Figure 3-1**). TTM with a goal of 32°C to 36°C (89.6°F to 96.8°F) core body temperature for at least 24 hours is recommended for patients who remain unconscious after ROSC (Figure 3-1). TTM is associated with both reduced mortality rates and improved neurological recovery after out-of-hospital cardiac arrest due to ventricular fibrillation and pulseless ventricular tachycardia. Although definitive evidence is lacking, TTM is also strongly recommended for nonshockable rhythms and for patients following in-hospital arrest because of the high morbidity and mortality associated with these circumstances. The options of TTM at lower and higher temperatures allows flexibility to tailor the treatment to the patient and avoid adverse effects of deeper hypothermia. Select group of post-cardiac arrest patients who are unconscious may benefit from TTM (**Table 3-1**).

Figure 3-1. Example of Targeted Temperature Management Algorithm[a]



Abbreviations: ROSC, return of spontaneous circulation; TTM, targeted temperature management; MAP, mean arterial pressure; SBP, systolic blood pressure

[a] Reproduced with permission from Lippincott, Williams & Wilkins. Seder DB, Van der Kloot TE. Methods of cooling: Practical aspects of therapeutic temperature management. *Crit Care Med. 2009*; 37:S211–S222.

Table 3-1	Considerations for Targeted Temperature Management

Patients for whom therapeutic hypothermia should be considered:

- Adult patients who remain comatose (ie, patients with a Glasgow Coma Scale Score less than 8 and/or patients who do not obey any verbal command after restoration of spontaneous circulation, but before the initiation of cooling) following successful resuscitation from a witnessed out-of-hospital cardiac arrest of presumed cardiac cause; in-hospital cardiac arrest survivors (of any initial rhythm) may also benefit.
- Patients with an initial rhythm of ventricular fibrillation or pulseless ventricular tachycardia; patients with initial rhythms of asystole or pulseless electrical activity may also benefit.
- May be used in hemodynamically unstable patients

Patients for whom therapeutic hypothermia should not be considered:

- Patients with advanced directives that proscribe aggressive care
- Patients with active non-compressible bleeding, but temperature management (<36°C) is reasonable

No specific time frame has been established for the start of TTM after cardiac arrest. However, it is generally recommended that the induction phase of cooling begin as soon as possible if the patient remains comatose. Although the target temperature should be reached as soon as possible, lifesaving cardiac procedures should not be delayed to initiate TTM. Active temperature management during rewarming is favored over passive rewarming. Avoid rebound fever. Warming should be performed slowly over 12 or more hours.

The most significant side effects of TTM are the potential for coagulopathy and increased risk of infection. The potentials for cardiac arrhythmias and hyperglycemia are also present.

A. Temperature Management Devices

Invasive and external devices are available for TTM, but no one strategy has proven to be superior. In the absence of specific temperature management devices, the use of iced saline and ice packs can be effective, although hypervolemia from excessive administration of iced saline should be avoided.

B. Potential Organ System Effects of TTM

Adverse effects of hypothermia are less likely if cooling to higher temperatures near 36°C.

- Neurologic: shivering
- Cardiac: dysrhythmias

- Renal: diuresis and potassium shifts
- Platelets: coagulopathy
- Skin: frostbite

C. Sedation and Pain Protocol

There are no specific pain or sedation protocols for TTM. Drug pharmacokinetics and pharmacodynamics are altered during therapeutic hypothermia. Aggressive attention to shivering is important; neuromuscular blockade may be necessary if conventional management fails.

VII. RESPIRATORY ARREST

Case Study

You are called to the bedside of an intubated ICU patient who has had a sudden onset of hypoxia and bradycardia. When you arrive, the pulse rate is 30 beats/min and Spo_2 values are 62%.

– What are the possible etiologies for the patient's deterioration?

– What steps should you take to optimize the patient's respiratory status?

A. Respiratory Arrest in the Nonintubated Patient

1. Immediate Concerns

One of the most common catastrophic events in nonintubated patients is respiratory arrest. These patients are typically found in asystole or pulseless electrical activity (PEA) but may be in ventricular fibrillation. The first responders should institute immediate basic life support, including bag-mask ventilation. Early endotracheal intubation allows for the most effective ventilation and oxygenation. Manual bag-mask ventilation with 100% oxygen until a provider experienced in endotracheal intubation arrives is preferable to prolonged, unsuccessful attempts at intubation.

2. Patient Assessment

In many instances, careful assessment of vital signs (including pulse oximetry), air movement, and work of breathing will indicate that respiratory impairment is present. Tachypnea progressing to bradypnea, paradoxical abdominal breathing, and progressively decreasing alertness may herald imminent respiratory arrest. Noninvasive respiratory monitoring may identify patients who are decompensating. Normal arterial blood gas measurements do not rule out the need for mechanical ventilatory support since decompensation can occur precipitously once respiratory muscle fatigue becomes manifest. Moreover, certain acute conditions (eg, asthma or pulmonary embolus) cause tachypnea. A normal P_{CO_2} in these instances portends advanced respiratory failure and fatigue.

B. Special Management Issues

1. Cardiac Arrest in Patients Receiving Mechanical Ventilation

If a patient suffers cardiac arrest while receiving mechanical ventilation, a complication related to ventilation must be suspected, especially if the initial cardiac rhythm is bradycardia or asystole. Etiologic possibilities include tension pneumothorax, ventilator failure or disconnection, or displacement or obstruction of the endotracheal tube. Patients should be disconnected from the ventilator immediately, and manual ventilation with 100% oxygen should be initiated while further assessment is undertaken. If high resistance to airflow is present, the endotracheal tube should be unsecured and checked for kinks, and attempts should be made to pass a suction catheter. Verification of tube placement with expired CO_2 monitoring is recommended as an adjunct to physical assessment. If tube position or patency is in question, the tube should be removed and the patient reintubated after being adequately oxygenated and ventilated by means of a bag-mask device. Tension pneumothorax also should be considered as a cause of high airway resistance. In instances of cardiac arrest, there is not sufficient time to obtain a chest radiograph to check for this possibility. The chest should be decompressed urgently with a needle placed at the level of the second intercostal space in the mid-clavicular position if breath sounds are absent or subcutaneous crepitus is noted.

2. Tension Pneumothorax

Patients with tension pneumothorax typically have hypotension and/or PEA with narrow complex tachycardia. Physical assessment may reveal jugular venous distension and ipsilateral decreased or absent breath sounds. Ipsilateral tympanitic percussion or

subcutaneous emphysema may be noted as well. In mechanically ventilated patients, airway pressures for normal tidal volume values will be high, and the ventilator high-pressure alarm limit may be exceeded. Resistance to bag-mask ventilation will increase as well. For patients with severe hypotension or PEA and findings consistent with tension pneumothorax, treatment should be instituted at once, without waiting for radiologic confirmation. Needle thoracostomy can be accomplished on the affected side by sterile placement of a 16- or 18-gauge catheter (a 23-gauge butterfly needle may be used in infants) through the anterior chest wall in the second intercostal space, at the midclavicular line. Successful decompression is associated with a rush of air, restoration of pulses, and a decrease in airway pressures in response to bag-mask or mechanical ventilation. *All needle thoracostomy procedures should be followed by standard tube thoracostomy* because this procedure can result in: 1) temporary relief of a tension pneumothorax; 2) creation of a pneumothorax if the presumption of a tension pneumothorax was wrong; or 3) no change in the patient's condition if the needle does not decompress the pleural space. Endotracheal tube obstruction (from a patient biting the tube or buildup of secretions) can mimic some of the findings described but does not usually cause severe hypotension or PEA.

VIII. ADVANCED LIFE SUPPORT IN THE CRITICAL CARE UNIT

A. General Issues

To be prepared for critical events such as cardiopulmonary arrest, clinicians should know the clinical background and status of patients in the critical care unit. They should review each patient's record during checkout rounds for signs of potential problems, such as electrolyte abnormalities. In addition, the clinical history and course may give clues to the etiology of a potential complication. For instance, a ventilated patient who is known to have a large emphysematous bulla and who suddenly develops PEA has a high likelihood of developing a tension pneumothorax secondary to bleb rupture. Making patient rounds at the beginning of each tour of duty also gives the staff an opportunity to clarify the resuscitation or code status of each patient.

B. Principal Concerns

Airway management and oxygenation/ventilation are important issues in the initial approach to acute decompensation of an ICU patient. Adequate oxygenation/ventilation should be evaluated by physical assessment as well as expired CO_2 monitoring (if

intubation is performed). *If there is evidence of abrupt cardiac or respiratory compromise, patients who are mechanically ventilated at the time of the arrest should be disconnected from the ventilator immediately and should receive 100% oxygen by bag-mask ventilation*. Early endotracheal intubation should be performed for those who are not intubated already; tube placement should be verified by physical assessment, chest radiograph, and exhaled CO_2 detection. Pulselessness can be verified by observing the arterial waveform if a functioning arterial line is in place or by carotid or femoral pulse checks. Chest compressions should be performed and early defibrillation for ventricular fibrillation should be undertaken as recommended by Advanced Cardiovascular Life Support guidelines.

Key Points

Cardiopulmonary/Cerebral Resuscitation

- The patient's resuscitation status should be in accordance with documented directives.
- Familiarity with recommendations for cardiopulmonary resuscitation is encouraged for all members of the resuscitation team.
- The person assuming the leadership role during resuscitation must effectively delegate specific duties and supervise the process of resuscitation.
- Resuscitation team members must accept delegation and remain focused upon those duties.
- Chest compressions should be optimized by ensuring a rate of at least 100/min, changing compressors every 2 minutes, continuing compressions before and after shock delivery, and minimizing interruptions.
- A complication related to mechanical ventilation should be suspected in patients who sustain an arrest while receiving ventilation, especially if the initial dysrhythmia is bradycardia or asystole.
- In patients with hypotension and/or PEA and findings consistent with tension pneumothorax, needle thoracostomy should be instituted without waiting for a chest radiograph to be performed

- Critically ill patients, or patients at risk of becoming critically ill, should be monitored for early signs of physiologic deterioration, and appropriate intervention should be instituted to avoid cardiopulmonary arrest.
- TTM is associated with both reduced mortality rates and improved neurological recovery after cardiac arrest.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Abella BS, Alvarado JP, Myklebust H, et al. Quality of cardiopulmonary resuscitation during in-hospital cardiac arrest. *JAMA*. 2005;293:305-310.
2. Bernard SA, Gray TW, Buist MD, et al. Treatment of comatose survivors of out-of hospital cardiac arrest with induced hypothermia. *N Engl J Med*. 2002;346:557-563.
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5. Kellum MJ, Kennedy KW, Barney R, et al. Cardiocerebral resuscitation improves neurologically intact survival of patients with out-of-hospital cardiac arrest. *Ann Emerg Med*. 2008;52:244-252.
6. Nadkarni VM, Larkin GL, Peberdy MA, et al. First documented rhythm and clinical outcome from in-hospital cardiac arrest among children and adults. *JAMA*. 2006;295:50-57.
7. Nolan JP, Soar J, Zideman DA, et al. European Resuscitation Council Guidelines for Resuscitation 2010 Section 1. Executive summary. *Resuscitation*. 2010;81:1219-1276.
8. Nunnally ME, Jaeschke R, Belligan GJ, et al. Targeted temperature management in critical care: A report and recommendations from five professional societies. *Crit Care Med*. 2011;39:1113-1125.

9. Seder DB, Van der Kloot TE. Methods of cooling: Practical aspects of therapeutic temperature management. *Crit Care Med*. 2009;37:S211–S222.

10. Hazinski MF, Nolan JP, Aickin R, et al. Part 1: Executive Summary: 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations. *Circulation*. 2015;132:S2-S39.

11. Jabre P, Belpomme V, Azoulay E, et al. Family presence during cardiopulmonary resuscitation. *N Engl J Med*. 2013;368:1008-1018.

12. Nielsen N, Wetterslev J, Cronberg T, et al. Targeted temperature management at 33°C versus 36°C after cardiac arrest. *N Engl J Med*. 2013;369:2197-2206.

Suggested Websites

1. Society of Critical Care Medicine. http://www.SCCM.org.
2. American Heart Association. http://www.americanheart.org.
3. *Circulation*. http://www.circulationaha.org.
4. European Resuscitation Council. http://www.erc.edu.

DIAGNOSIS AND MANAGEMENT OF ACUTE RESPIRATORY FAILURE

Objectives

- Define and classify acute respiratory failure.
- Describe the pathophysiology and manifestations of acute respiratory failure.
- Review oxygen supplementation strategies in acute respiratory failure.

Case Study

A 75-year-old man with a long history of smoking, chronic lung disease, and treatment noncompliance is brought to the emergency department by his daughter, who says that he complained of progressive dyspnea overnight. The patient is awake, alert, and in moderate respiratory distress, with evident use of accessory muscles during inspiration and expiration and a respiratory rate of 30 breaths/min. There are audible expiratory wheezes. You are called to assess the patient and initiate treatment.

– What tests would be useful to evaluate the severity of the patient's condition?

– Which oxygen supplementation device should be used?

– What pharmacologic treatment should be initiated?

I. INTRODUCTION

Acute respiratory failure (ARF) is one of the leading causes of admission to the ICU. It is defined as the inability of the respiratory system to meet the oxygenation, ventilation, or metabolic requirements of the patient. The pulmonary system is involved in two crucial functions: elimination of carbon dioxide (CO_2) and oxygenation of the blood.

There are three types of respiratory failure: hypoxemic, hypercapnic, and mixed. Hypoxemic respiratory failure is defined by a room air Pa_{O_2} of ≤50 to 60 mm Hg (≤6.7-8 kPa) or an abnormal ratio of Pa_{O_2} to fraction of inspired oxygen (Pa_{O_2}:F_{IO_2}, or P:F ratio; see below). This abnormality of Pa_{O_2} should exist in the absence of intracardiac right-to-left shunting. Hypercapnic respiratory failure is defined by a Pa_{CO_2} ≥50 mm Hg (≥6.7 kPa) that is not due to respiratory compensation for metabolic alkalosis. Mixed respiratory failure has features of both hypercapnia and hypoxemia and is a common form of respiratory failure in critically ill patients. Respiratory failure is considered chronic once the renal system begins to compensate by retaining bicarbonate. This usually occurs within a few days of persistent hypercapnia and the resulting respiratory acidosis. Frequently, in patients with chronic lung disease, ARF may be superimposed on chronic respiratory insufficiency. The acute component in such circumstances is distinguishable from the chronic component by the degree of respiratory acidosis in relation to Pa_{CO_2} and knowledge of baseline oxygen requirements, Pa_{CO_2} levels, and bicarbonate values.

II. CAUSES OF ACUTE RESPIRATORY FAILURE

Acute respiratory failure develops in a variety of clinical settings. It may result from primary pulmonary insults or from other systemic nonpulmonary disorders, as summarized in **Table 4-1**. Diseases of the central nervous system, neuromuscular system, upper and lower airways, pulmonary parenchyma, pulmonary vasculature, thoracoabdominal cavity, and cardiovascular system may all give rise to ARF.

Table 4-1 Causes of Respiratory Failure

DISORDERS ASSOCIATED WITH ABNORMAL OXYGEN ONLOADING (HYPOXEMIC RESPIRATORY FAILURE) **Lower Airway and Parenchyma**		
NEOPLASM	TRAUMA	OTHER
INFECTIONS	Pulmonary contusion	Bronchospasm
Viral	Pulmonary laceration	Heart failure
Bacterial		Acute respiratory distress syndrome
Fungal		Interstitial lung disease
Mycoplasmal		Atelectasis
Other		Cystic fibrosis
DISORDERS ASSOCIATED WITH INADEQUATE CARBON DIOXIDE OFFLOADING (HYPERCAPNIC RESPIRATORY FAILURE) **Brain**		

DRUGS Opioids Benzodiazepines Propofol Barbiturates General anesthetics Poisons	METABOLIC Hyponatremia Hypocalcemia Alkalosis Myxedema	NEOPLASMS INFECTIONS Meningitis Encephalitis Abscess Polio West Nile myelitis	INCREASED INTRACRANIAL PRESSURE OTHER Central alveolar hypoventilation Central sleep apnea

Nerves and Muscles

TRAUMA Spinal cord injury Diaphragmatic injury	DRUGS/POISONS Neuromuscular blocking agents Aminoglycoside antibiotics Arsenic Strychnine Botulism	METABOLIC Hypokalemia, hyperkalemia Hypophosphatemia Hypomagnesemia	NEOPLASM INFECTIONS Tetanus West Nile myelitis	OTHER Motor neuron disease Myasthenia gravis Multiple sclerosis Muscular dystrophy Guillain-Barré syndrome Botulism

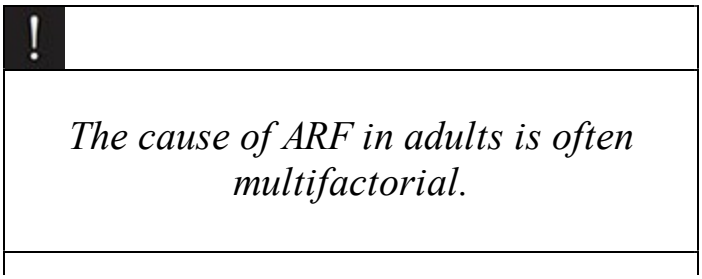
Upper Airway

TISSUE ENLARGEMENT Tonsil and adenoid hyperplasia Malignant neoplasm Polyps	INFECTIONS Epiglottitis Laryngotracheitis TRAUMA	OTHER Bilateral vocal-cord paralysis Laryngeal edema Tracheomalacia Goiter Cricoarytenoid arthritis Obstructive sleep apnea

Chest Bellows

TRAUMA	OTHER CONTRIBUTING FACTORS	
Rib fractures Flail chest Burn eschar	Kyphoscoliosis Scleroderma Spondylitis Pneumothorax Pleural effusion	Fibrothorax Supine position Obesity Pain Ascites

Hypoxemic respiratory failure is often seen in patients with severe pneumonia, acute lung injury, or acute pulmonary edema, disorders that interfere primarily with adequate oxygenation of the blood as it circulates through the alveolar capillaries. Hypercapnic respiratory failure is seen in patients with severe airflow obstruction, central respiratory failure, or neuromuscular respiratory failure. Hypercapnia most often results from inadequate alveolar ventilation, which causes ineffective CO_2 clearance.



The following are common ICU scenarios that lead to ARF:

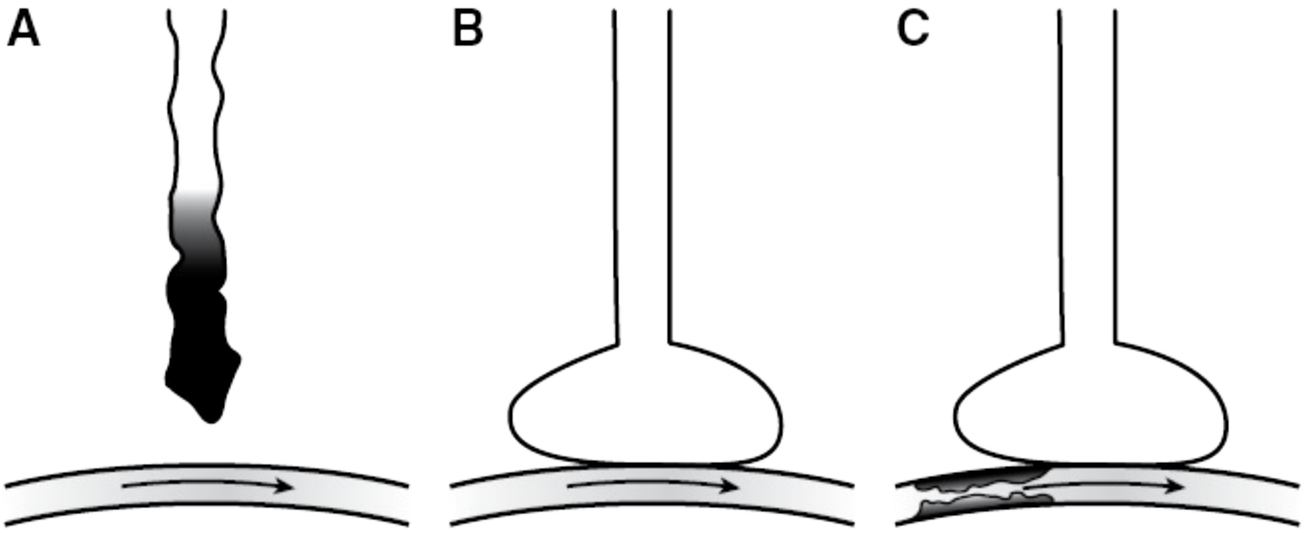
- Exacerbations of chronic obstructive pulmonary disease (COPD), characterized by thick mucopurulent secretions as well as bronchospasm, are often associated with both hypoxemic and hypercapnic acute respiratory failure (ie, mixed ARF).
- Pneumonia is most commonly associated with hypoxemic respiratory failure, although it also can be associated with hypercapnic respiratory failure, especially in the setting of other diseases such as COPD.
- Acute respiratory distress syndrome is a manifestation of a systemic inflammatory response caused by pulmonary or nonpulmonary injury or disease. The predominantly hypoxemic respiratory failure is caused primarily by an increased shunt fraction due to alveolar filling.
- Traumatic brain injury is associated with predominantly hypercapnic respiratory failure, although it can be complicated by hypoxemic respiratory failure in the setting of concurrent aspiration, pulmonary contusions, neurogenic pulmonary edema, or chronic pulmonary disease.
- Overdose with central nervous system-depressing agents, such as benzodiazepines, opioids, or barbiturates, presents with alveolar hypoventilation and thus acute hypercapnic respiratory failure.
- Decompensated congestive heart failure is associated with predominantly hypoxemic failure (secondary to alveolar filling and increased shunt); however, hypercapnic respiratory failure may also occur in severe exacerbations or in the presence of pulmonary disease.

III. PATHOPHYSIOLOGY OF ACUTE RESPIRATORY FAILURE

A. Hypoxemia

The most common underlying physiologic abnormality in hypoxemic respiratory failure is a mismatch of alveolar ventilation $\dot{V}$ and pulmonary perfusion $\dot{Q}$, as illustrated in **Figure 4-1**. The mismatch of ventilation and perfusion, where ventilation is decreased relative to perfusion, is called low $\dot{V}/\dot{Q}$.

Figure 4-1. Ventilation and Perfusion Matching in the Lung



A, At one end of the pathologic continuum, areas of limited ventilation relative to perfusion produce shunt effect and hypoxemia. **B**, Ventilation and perfusion are matched in the normal lung. **C**, At the opposite end of the continuum, areas of better ventilation than perfusion produce dead space effect.

$\dot{V}/\dot{Q}$ matching is of particular importance to oxygenation of blood as opposed to elimination of CO_2 (discussed in Section IV) because of the kinetics of the hemoglobin oxygen dissociation curve (**Chapter 6**, **Figure 6-1** for the oxyhemoglobin dissociation curve). Lung areas with high $\dot{V}/\dot{Q}$ ratios, which provide a high Pa_{O_2}, cannot compensate for areas with a low $\dot{V}/\dot{Q}$ ratio (providing low Pa_{O_2}) as the hemoglobin molecule is already about 90% saturated at a Pa_{O_2} of about 60 mm Hg. The admixture of poorly oxygenated blood returning from abnormal alveoli dilutes oxygenated blood from more normal lung units, resulting in systemic hypoxemia. The hypoxemia caused by $\dot{V}/\dot{Q}$ mismatch is usually easily corrected by supplemental oxygen.

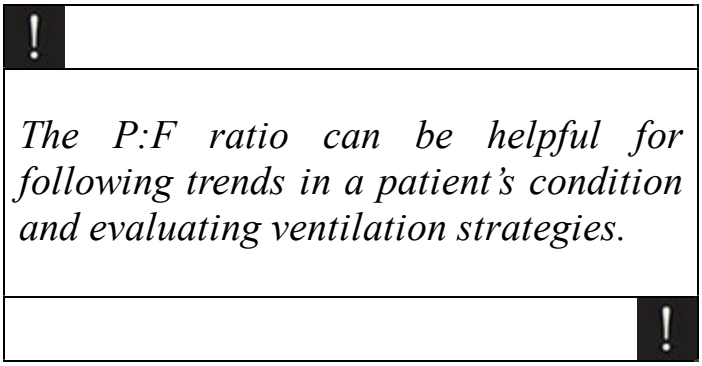
Disease processes that cause progressive obstruction of distal airways, alveolar filling, or atelectasis (eg, pneumonia, aspiration, pulmonary edema) result in a decrease in the amount of oxygen available in distal airways for uptake through the pulmonary capillaries. Through hypoxic pulmonary vasoconstriction, blood flow to such abnormal lung units decreases, but this decline is of lesser magnitude than the decrease in oxygen availability. This allows for a greater proportion of deoxygenated blood (venous admixture) to return to the left side of the heart.

One extreme of $\dot{V}/\dot{Q}$ mismatch is shunt, as there is perfusion of the unventilated lung. In diseases that cause diffuse alveolar flooding (eg, acute respiratory distress syndrome), refractory hypoxemia may be due to shunt physiology. Treatment of hypoxemia due to $\dot{V}$

/Q̇ mismatch should be directed towards treating the underlying cause such as infections, reversing airway obstruction, reopening (recruiting) atelectatic lung zones, and preventing closure (de-recruitment) of the affected lung units. Oxygen therapy and/or mechanical ventilation are cornerstones in providing support until such time that the cause of V̇ /Q̇ mismatch has been reversed.

Other, less common causes of hypoxemia include:

- Decreased diffusion of oxygen across the alveolocapillary membrane complex because of interstitial edema, inflammation, fibrosis, etc.
- Alveolar hypoventilation
- High altitude with low inspired partial pressure of oxygen



Diffusion abnormality is rarely the primary cause for hypoxemia as oxygen transport across the alveolocapillary membrane is generally perfusion limited and not diffusion limited; however, in cases such as increased cardiac output and tachycardia, diffusion may be limited when the transit time across pulmonary capillaries is reduced. Therapy for diffusion abnormalities, in addition to maintaining adequate circulating volume, includes treatment of the cause of interstitial pathology (ie, diuretics for cardiogenic pulmonary edema, corticosteroids for inflammatory disorders). Ensuring adequate minute ventilation will correct hypoxemia that is solely due to hypoventilation. High altitude is a rare cause of acute hypoxemia in patients. As a compensatory strategy, increasing oxygen supplementation (F_{IO_2}) while the cause of the hypoxemia is sought and corrected may improve oxygenation.

Numerous methods for quantifying hypoxemia have been proposed to provide a means of following the degree of hypoxemia and to communicate this information to other providers. The P:F ratio (where Pa_{O_2} is measured as mm Hg and F_{IO_2} is the fraction of inspired oxygen) is a commonly used method for quantifying the degree of patient hypoxemia. It requires accurate assessment of F_{IO_2}, which is difficult in the nonintubated patient. Calculating the P:F ratio is a simple method for assessing the degree of

hypoxemia and following it over time. A normal P:F ratio ranges between 300 and 500 mm Hg, with values below 300 mm Hg indicating abnormal gas exchange and values below 200 mm Hg indicating severe hypoxemia. However, one must be cognizant of the fact that Pa_{O_2} — hence, the P:F ratio — can be greatly modified by the application of positive end-expiratory pressure and other recruitment maneuvers. Thus, different P:F ratios may be obtained for the same amount of F_{IO_2}.

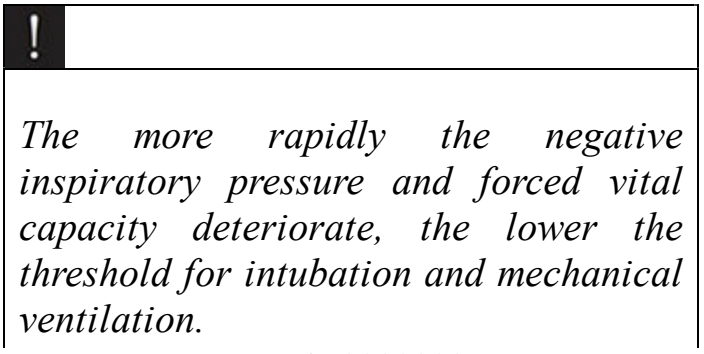
B. Hypercapnia

Hypercapnic respiratory failure is caused by either excess CO_2 production or decreased effective alveolar ventilation. Alveolar minute ventilation (V_A) is determined by the tidal volume (V_T), and the respiratory rate frequency (f). V_D is dead space.

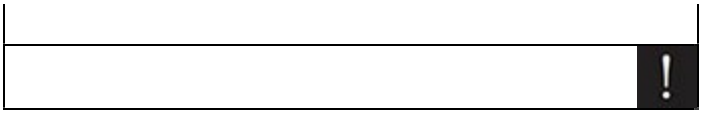
$$V_A = (V_T - V_D)f$$

Hypercapnia, resulting from either decreased V_T or the respiratory rate frequency, occurs with drug ingestion, anesthesia, depression of the medullary center for respiration, and fatigue, for example. An elevated Pa_{CO_2} normally increases ventilatory drive. Therefore, hypercapnic respiratory failure implies that the patient is unable to sustain minute ventilation ($f \times V_T$).

Treatment of decreased V_T or respiratory rate may require reversal of sedation or other drugs, intubation/mechanical ventilation to rest fatigued muscles, nutrition, respiratory stimulants, or treatment of other possible primary causes. Measures of ventilatory mechanics, such as peak negative inspiratory pressure and forced vital capacity, monitor a patient's course and may signal when endotracheal intubation and mechanical ventilation are warranted, especially in neuromuscular disorders such as myasthenia gravis and Guillain-Barré syndrome. A single measurement is less useful than measurements made over time. Negative inspiratory pressures below –20 to 25 cm H_2O or forced vital capacity <10 mL/kg, or both, should raise concern that a patient's ventilatory mechanics may be sufficiently impaired to warrant tracheal intubation and mechanical ventilation.



The more rapidly the negative inspiratory pressure and forced vital capacity deteriorate, the lower the threshold for intubation and mechanical ventilation.



Increased physiologic dead space (V_D) may also produce hypercapnia and is another type of mismatch illustrated in **Figure 4-1**. When gas flow to and from airways remains adequate but blood flow is absolutely or relatively diminished, CO_2 does not have the opportunity to diffuse out of the pulmonary circulation, and CO_2-rich blood is returned to the left atrium. Increased dead space ventilation may occur in respiratory muscle fatigue from any cause, leading to rapid shallow breathing. Increased V_D may also be seen in hypovolemia, pulmonary embolism, poor cardiac output, or when the regional airway pressure is relatively higher than the regional perfusion pressure, reducing pulmonary blood flow in that area.

Strategies to reduce dead space may include reduction in peak or mean airway pressures, if the patient is receiving mechanical ventilation, augmentation of intravascular volume and/or cardiac output, or treatment of other causes for limited pulmonary blood flow. It may be possible to compensate for hypercapnia due to high V_D by modifying parameters to increase minute ventilation during mechanical ventilation while the cause of hypercapnia is sought and corrected. Because of the high solubility of CO_2, a diffusion barrier rarely ever occurs. Increased CO_2 production may contribute to hypercapnia secondary to either excess carbohydrate nutritional calories or extreme hypercatabolic conditions (eg, burns, hyperthyroidism, persistent fever).

C. MIXED RESPIRATORY FAILURE

Patients commonly demonstrate characteristics of both pathophysiologic categories of ARF during the course of illness. An understanding of the underlying pathophysiology of each, therefore, is necessary for planning therapeutic support. Several related disease processes often act in concert or synergistically to compound respiratory failure. For example, the patient with chronic pulmonary disease and a large dead space often has associated heart failure, which increases $\dot{V}/\dot{Q}$ mismatching and worsens hypoxemia.

IV. MANIFESTATIONS OF ACUTE RESPIRATORY FAILURE

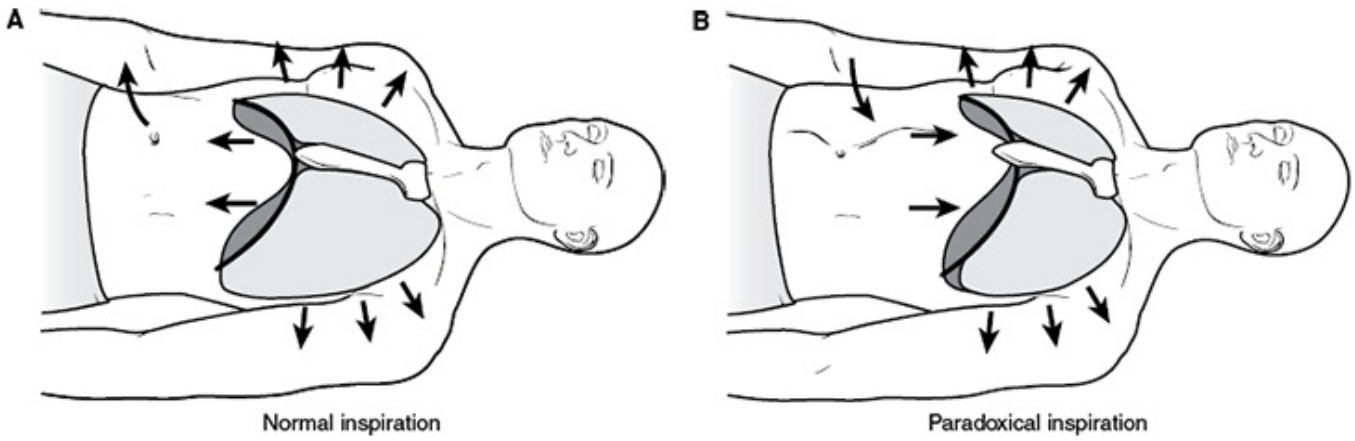
A. Clinical Presentation of Respiratory Distress

Clinical manifestations of respiratory distress commonly include signs and symptoms of

hypoxemia, hypercapnia, or both. These include:

- Altered mental status ranging from agitation to somnolence
- Evidence of increased work of breathing, such as nasal flaring in infants, use of accessory respiratory muscles, intercostal/suprasternal/supraclavicular muscle retraction, tachypnea, hyperpnea, or a paradoxical or dysynchronous breathing pattern (**Figure 4-2**)
- Bradypnea
- Cyanosis of mucosal membranes (eg, tongue, mouth) or nail beds
- Diaphoresis, tachycardia, hypertension, and other signs of catecholamine release

Figure 4-2. Normal Versus Abnormal Respiration



A, The abdominal wall moves outward as the diaphragm moves downward in normal inspiration. **B**, With respiratory muscle fatigue, the diaphragm becomes flaccid and moves upward during inspiration resulting in inward movement of the abdominal wall.

B. Diagnostic Tests

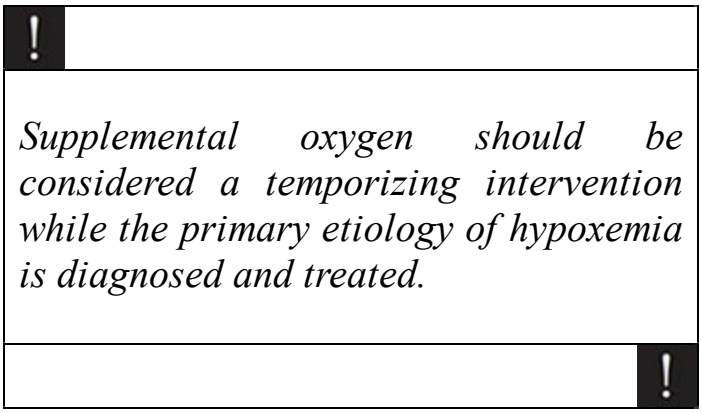
Pulse oximetry can be used to rapidly evaluate oxygenation in a patient with respiratory distress by estimating the arterial oxyhemoglobin saturation (**Chapter 6**). However, pulse oximetry provides no assessment for hypercapnia. Arterial blood gas analysis is commonly used in severely ill patients to determine the two primary measures of respiratory failure, the Pa_{O_2} and Pa_{CO_2}, as well as pH. Additional tests such as electrolytes, hematocrit, and drug levels may provide clues to the underlying etiology of ARF. Chest radiography in combination with these laboratory tests is invaluable in suggesting the underlying pathophysiology of ARF.

V. MANAGEMENT CONSIDERATIONS

A. Oxygen Supplementation

Most patients with ARF require supplemental oxygen. Oxygen transfer from alveolar gas to capillary blood occurs by diffusion across the alveolar-capillary membrane and is driven by the oxygen partial-pressure gradient between the partial pressure of alveolar oxygen (P_{AO_2}) and the P_{O_2} of the pulmonary capillary blood. In most cases of ARF, the P_{AO_2} can be substantially increased by use of supplemental oxygen, thus increasing the gradient across the membrane and improving the Pa_{O_2}.

Supplemental oxygen can be provided by a variety of devices (**Figure 4-3**). The effectiveness of each is determined by its capacity to deliver sufficient oxygen at a high enough flow rate to match the patient's spontaneous inspiratory flow rate. Matching between the flow capacity of the oxygen device and the patient's inspiratory flow demand determines how much room air is entrained by the nonintubated patient breathing in an open system. Any entrained room air ($F_{IO_2} = 0.21$) will dilute (decrease) the F_{IO_2} of the delivered gas in such a way that the tracheal F_{IO_2}, and hence P_{AO_2}, may be considerably lower than the F_{IO_2} delivered from the oxygen source. Therefore, oxygen-supplement systems are usually classified as high oxygen (capable of delivering up to 100% oxygen), controlled oxygen (set oxygen percentage), or low oxygen. Similarly, the devices are also categorized as either high flow, moderate flow, or low flow, reflecting the flow-delivery capacity of the gas at the preset F_{IO_2} level.

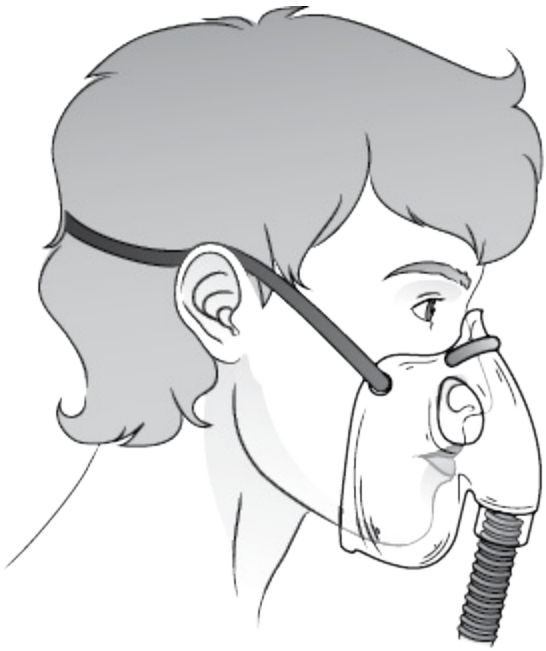


For example, a tachypneic and hyperpneic patient will have a high inspiratory flow rate during each breath. In such cases, hypoxemia is not likely to respond well to oxygen supplementation by nasal cannula because it is a low-oxygen, low-flow system and cannot match the patient's high inspiratory flow rate. Room air will be entrained during

inspiration, and the tracheal F_{IO_2} will be reduced. A high-oxygen, high-flow system should be selected for this type of patient.

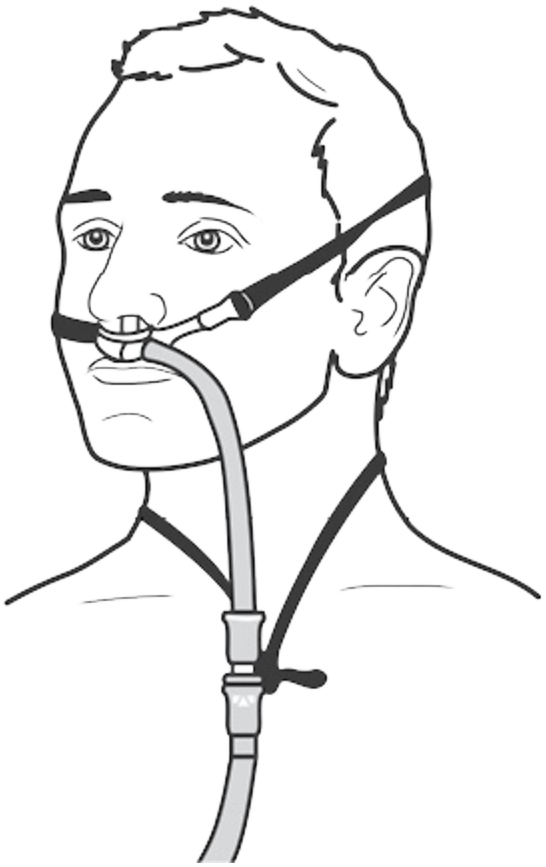
Figure 4-3. Oxygen Delivery Devices

A. Venturi Mask



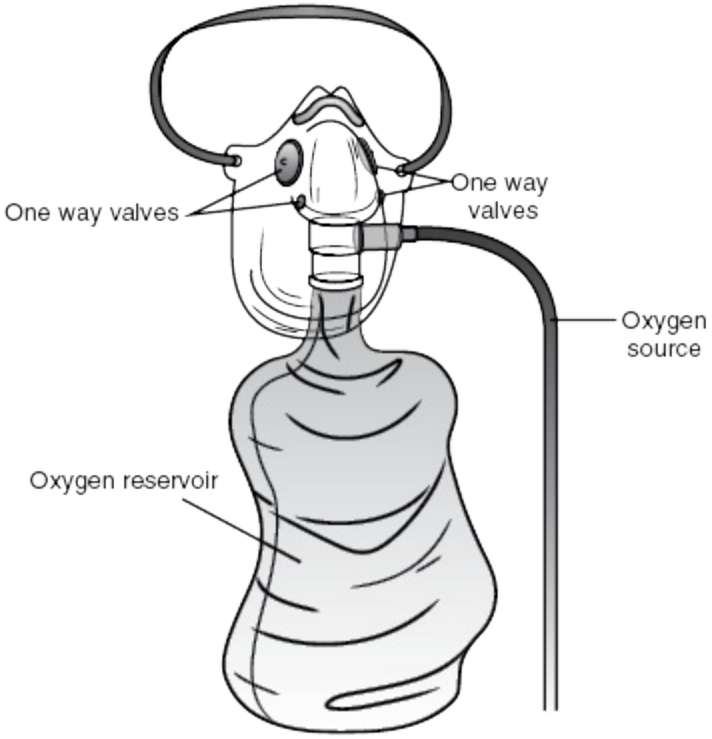
- Delivers humidified oxygen (aerosol adapter can be added)
- F_{IO_2} is set by entrainment dial on mask
- Low concentrations = 24%, 26%, 28%, 31%
- High concentrations = 35%, 40%, 50%

B. High-flow Nasal Cannula



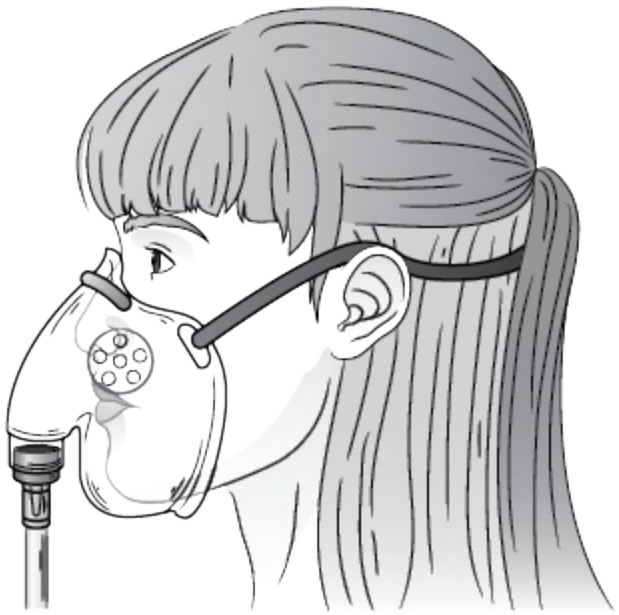
- Uses up to 100% oxygen source
- Flow rate <60 L/min

C. Non-rebreathing Mask



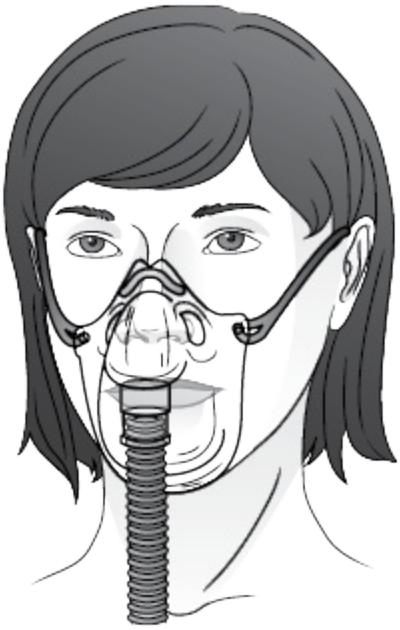
- Delivers non-humidified oxygen
- Used for emergency delivery
- F_{IO_2} range = 60 - ?100%
- Reservoir bag provides 100% F_{IO_2} and minimizes room air dilution
- Flap valves minimize entrainment of room air (which will dilute F_{IO_2})
- Flow rate is adjusted according to the patient's ventilator pattern to keep reservoir bag inflated

D. Simple Oxygen Mask



- Delivers humidified oxygen
- Minimum flow rate = 6 L/min (to clear exhaled CO_2 from mask)
- Approximate concentrations: 6 L = 40%; 7 L = 50%; 8L = 60%

E. Aerosol Mask

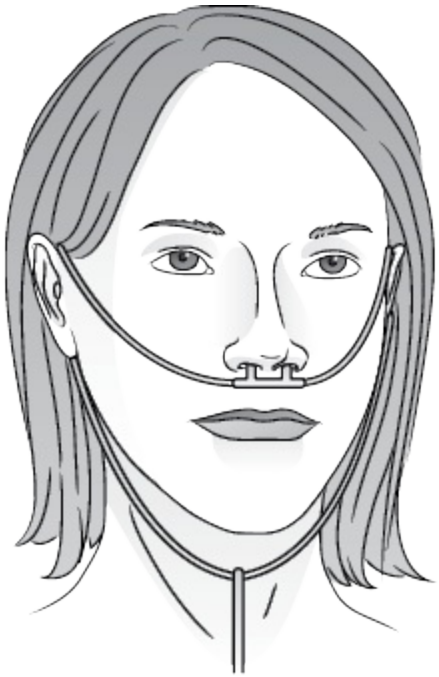


- Delivers cool, aerosolized oxygen or air
- F_{IO_2} is set by dial on oxygen adapter
- Maximum F_{IO_2} = 40%-60%
- Minimum flow rate = 8 L/min

F. Tracheostomy Mask

- Delivers heated, aerosolized oxygen or air
- F_{IO_2} is set by dial on blender
- Maximum F_{IO_2} = 40%-60%
- Minimum flow rate = 8 L/min

G. Nasal Cannula



- Delivers humidified oxygen
- Nasal passages must be patent

- Blender setup: F_{IO_2} is set by dial; 1-2 L flow can be used as continuous positive airway pressure for infants
- Wall setup: F_{IO_2} is set by flow rate
- Approximate F_{IO_2} (if respiratory rate and tidal volume are normal):

Adult
1L = 24% 4L = 36%
2L = 28% 5L = 40%
3L = 32% 6L = 44%

H. Face Tent

- Delivers cool, aerosolized oxygen or air
- Loose fit under the chin for patient comfort, speaking, etc.
- F_{IO_2} is set by dial on oxygen adapter (concentration is unstable)
- Maximum F_{IO_2} = 40%-50%
- Minimum flow rate = 8 L/min

1. Low-Flow Nasal Cannula

Short prongs of the nasal cannula are inserted into the nares. Oxygen (100%) is delivered through the cannula, but at a rate between 0.5 and 5 L/min. The resulting F_{IO_2} depends on the patient's minute ventilation and, therefore, cannot be precisely controlled, but the maximal tracheal F_{IO_2} is not likely to exceed 0.4 to 0.5 (40% to 50%). Higher flow rates do not result in much higher F_{IO_2} levels and have a drying and irritating effect on nasal mucosa. The nasal cannula is comfortable and well tolerated by many patients with ARF in whom precise control of F_{IO_2} is not necessary. It is a low-

flow, low-oxygen device.

2. High-Flow Nasal Cannula

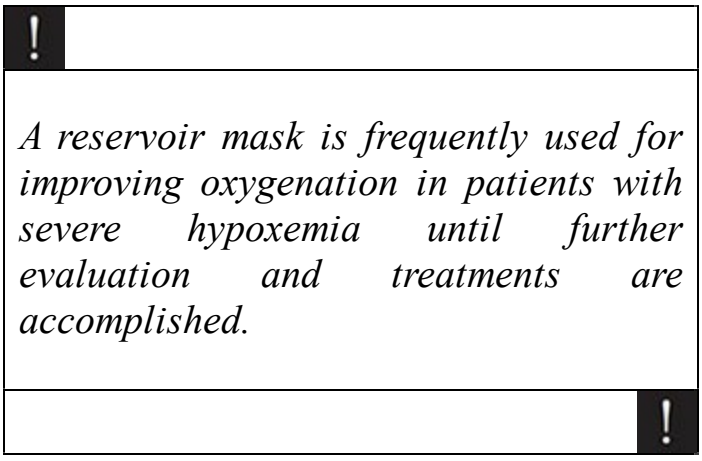
In contrast to the low-flow cannulas, high-flow nasal cannula systems involve delivery of heated and humidified oxygen via special devices (eg, Vapotherm®, Optiflow™) at rates up to 60 L/min in adults. These devices may be better tolerated than face masks in terms of comfort. They also provide higher amounts of F_{IO_2} (0.32-1.0) in patients with high minute ventilation requirements by matching the patients' inspiratory demands and minimizing air dilution. These devices may generate positive end-expiratory pressure that is difficult to measure and have the potential for causing barotrauma.

3. Air-Entrainment Face Mask

Air-entrainment masks (also called Venturi masks) deliver oxygen through a jet-mixing device that increases the velocity of oxygen and causes a controlled entrainment. The F_{IO_2} can be more precisely controlled from 0.24 to 0.5 (24% to 50%) at high-flow rates simply by selecting the interchangeable jet nozzle and adjusting the oxygen flow rate. It is a high-flow, controlled-oxygen device.

4. Aerosol Face Mask

The commonly used aerosol face mask combines a variable oxygen setting and moderate flows. The mask, which has large side holes, is attached by large-bore tubing to a nebulizer that blends 100% oxygen and room air to deliver gas at a preset F_{IO_2} level. Flow matching can be evaluated by observing the patient during spontaneous breathing. If the entire aerosol mist disappears from the mask during inhalation, the patient's inspiratory flow demands are probably exceeding the capacity of the nebulizer and room air is being entrained. The aerosol face mask is a variable oxygen, moderate-flow device.



5. Reservoir Face Mask

The reservoir face mask incorporates a reservoir bag from which the patient breathes. This bag is filled with 100% oxygen from a supply source. The flow rate is adjusted so that the bag remains completely or partially distended throughout the respiratory cycle. When the mask is properly applied, oxygen delivery to the nonintubated patient can be maximized but rarely exceeds an F_{IO_2} of 0.6 to 0.9. The reservoir face mask is a high-oxygen, high-flow device.

6. Resuscitation Bag-Mask Unit

Although not commonly considered an oxygen-supplement device, bag-mask units are usually included with other emergency equipment and, therefore, are readily accessible. When the mask is held firmly over the patient's face, room air entrainment is largely excluded. If the oxygen flow to the bag is kept high (≥15 L/min), a high-oxygen supply is provided at sufficient flow. The resuscitation bag need not be compressed to supply oxygen. It is a high-oxygen, high-flow device.

B. Pharmacologic Adjuncts

Many diseases that cause ARF produce similar anatomic and physiologic derangements, including bronchial inflammation, mucosal edema, smooth muscle contraction, and increased mucus production and viscosity. Each of these processes may contribute to obstruction of airway gas flow, increased airway resistance, mismatch, and elevated V_D. Some pharmacologic agents may be helpful in the care of such patients and may directly alter shunt or dead-space effects.

1. β_2-Agonists

Inhaled β_2-agonists are important therapy in patients with ARF secondary to many causes. Stimulation of β_2-adrenergic receptors causes bronchial and vascular smooth-muscle relaxation. These agents are typically administered by metered-dose inhaler or by intermittent or continuous nebulization (**Table 4-2**). On rare occasions, in very critically ill patients with obstructive airway disease, β_2-agonists are administered by both inhalation and subcutaneous injection. Long-acting inhaled agents do not have a role in the management of patients with acute respiratory deterioration. Racemic epinephrine aerosol is an established therapy for upper airway obstruction in children with croup and is also used for laryngeal edema in adults.

Table 4-2 Pharmacologic Agents for Obstructive Airway Disease

Drug	Preparation	Route of Administration	Dosage
Albuterol	0.05% solution	Inhaled (aerosol)	*Adult:* 2.5–5 mg q 2–4 h[a] *Pediatric:* 0.05–0.15 mg/kg q 4–6 h[a]
	MDI (90 µg/puff)	Inhaled	*Adult:* 1–2 puffs q 2–4 h[a] *Pediatric:* 1–2 puffs q 4–6 h[a]
Levalbuterol	0.31, 0.63, or 1.23 mg/unit dose solution	Inhaled (aerosol)	*Adult and children* ≥12 y: 0.63–1.25 mg q 6–8 h *Pediatric* (6–11 y): 0.31–0.63 mg q 6–8 h; more aggressive dosing may be used in acute exacerbations
	MDI (45 µg/puff)	Inhaled	*Adult:* 1–2 puffs q 4–6 h *Pediatric* (age ≥4 y):1–2 puffs q 4–6 h
Metaproterenol Sulfate	5% solution	Inhaled (aerosol)	*Adult:* 0.3 mL q 2–4 h[a] *Pediatric:* 0.25–0.5 mg/kg q 2–4 h[a]
	MDI (0.65 µg/puff)	Inhaled	*Adult:* 2–3 puffs q 4–6 h[a] *Pediatric:* 1–3 puffs q 4–6 h[a]
Terbutaline	MDI (0.2 µg/puff)	Inhaled	*Adult:* 1–2 puffs q 4–6 h[a] *Pediatric:* 1–2 puffs q 4–6 h[a]
	0.1% solution	Subcutaneous	*Adult:* 0.2–0.4 mL; repeat in 15–30 min *Pediatric:* 0.2 mg/kg; maximum 6 mg
Epinephrine	1 mg/mL (1:1000)	Subcutaneous	*Adult:* 0.1–0.5 mg; repeat in 20–30 min *Pediatric:* 0.01 mg/kg
Inhaled Epinephrine	1 mg/mL (1:1000)	Inhaled	*Adult:* 2.5-5 mL q 3 h *Pediatric:* >4 y: 2.5-5 mL q 3 h; <4 y: 2.5 mL q 3 h
Ipratropium	0.025% solution	Inhaled (aerosol)	*Adult:* 500 µg q 6–8 h; *Pediatric:* Infant and child: 250 µg q 6–8 h: >12 y: 250–500 µg q 6–8 h
	MDI (18 µg/puff)	Inhaled	*Adult:* 2–4 puffs q 6 h *Pediatric:* 1–2 puffs q 8 h

Abbreviations: q, every; MDI, metered-dose inhaler; NS, normal saline

[a]In patients with severe asthma, frequency of administration of inhaled β-agonists should be guided by response to therapy and risk for side effects. Therapy is routinely initiated with three treatments every 20 minutes. Further therapy adjustments are then based on response. Continuous nebulization may also be employed. Caution should be exercised when considering use of continuous nebulized β_2-agonists, particularly in older patients and those with underlying cardiac disease.

2. Anticholinergic Agents

Ipratropium bromide competes with acetylcholine at the bronchial receptor site, resulting in bronchial smooth-muscle relaxation. This agent is delivered by metered-dose inhaler or nebulization (**Table 4-2**). Ipratropium has a more delayed onset of

action than β_2-agonists and has more consistent bronchodilatory effects in COPD than in asthma. The addition of ipratropium to albuterol appears to have an additive benefit in approximately 30% of asthma patients. Tiotropium is a long-acting anticholinergic bronchodilator that has sustained effects in COPD patients, but its use in acute exacerbations is not recommended.

3. Corticosteroids

The central role of inflammation in obstructive airway disease is well established, and the benefit from aggressive corticosteroid use in asthmatic patients with ARF is well documented. In addition, corticosteroids may decrease β-receptor tachyphylaxis. Limited consensus exists on dosing schedules in asthma. Doses of methylprednisolone of 80 mg/24 h have been as effective as >360 mg/24 h. Some clinicians use doses equivalent to those given for asthma when treating COPD, whereas others begin with doses equivalent to 1 mg/kg/24 h, adjusting as patient response dictates. The intravenous and oral routes are equally effective. Careful monitoring of corticosteroid side effects is warranted. Acute myopathies have been described after moderate to high dosages of corticosteroids in patients with COPD and/or asthma. After the acute exacerbation, inhaled corticosteroids are often useful adjuncts to therapy and may allow reduction in systemic corticosteroid dosage. However, routine use of inhalational agents is not recommended in the setting of acute severe bronchospasm.

4. Antibiotics

Bacterial infection (bronchitis/pneumonia) frequently precipitates ARF. Antibiotics should be used when there is clinical suspicion that bacterial pulmonary infection is present (eg, change in sputum characteristics, pulmonary infiltrates on the chest radiograph, fever, leukocytosis), and they should be chosen to effectively treat usual pathogens (**Chapter 11**). Therapy should be subsequently adjusted when culture and sensitivity data become available.

Several randomized trials have compared clinical outcomes in patients hospitalized with acute exacerbation of COPD and have shown antibiotic treatment has been associated with decreased risk of adverse outcomes. When the decision is made to use antibiotics, it is important to distinguish a simple from a complicated case of acute exacerbation of COPD and a 5-day course is usually recommended.

C. Miscellaneous Agents and Treatments

Agents to hydrate or otherwise alter the composition, elasticity, or viscosity of mucus

have been used, although their efficacy has not been demonstrated except in selected patient groups (eg, patients with cystic fibrosis). Examples of these agents include mucolytics such as acetylcysteine or propylene glycol, bronchorrheic agents such as saturated solution of potassium iodide or glyceryl guaiacolate, and alkalinizing agents such as aerosolized sodium bicarbonate.

Postural drainage, chest physical therapy, nasotracheal suctioning, incentive spirometry, intermittent positive pressure breathing, and cough/deep-breathing exercises have long been used. Also available are newer measures such as positive expiratory pressure therapy, vest devices (high-frequency chest oscillator), and mattress percussion devices. Many of these modalities may be applied to treat specific symptoms of ARF or the cause of respiratory failure. The effectiveness and positive impact of the contributions of the bedside nurse or the respiratory care practitioner and the avoidance of intubation/mechanical ventilation should not be underestimated.

Key Points

Diagnosis And Management Of Acute Respiratory Failure

- Acute respiratory failure is classified as hypoxemic, hypercapnic, or mixed. Arterial blood gas measurements are the primary assessment tool for determining this classification.
- The most common pathophysiologic mechanism for hypoxemic acute respiratory failure is ventilation/perfusion mismatch.
- Hypercapnic acute respiratory failure is primarily the result of a change in one or more determinants of the alveolar minute ventilation equation: tidal volume, respiratory frequency, and physiologic dead space.
- Oxygen supplementation is commonly used to treat hypoxemia. The oxygen supply device that is chosen must be capable of matching the oxygen and respiratory flow demands of the patient.
- Pharmacologic and therapeutic adjuncts should be considered when treating patients with acute respiratory failure.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Dolovich MB, Ahrens RC, Hess DR, et al. Device selection and outcomes of aerosol therapy: Evidence-based guidelines: American College of Chest Physicians/American College of Asthma, Allergy and Immunology. *Chest*. 2005;127:335-371.

2. Manser R, Reid D, Abramson M. Corticosteroids for acute severe asthma in hospitalized patients. *Cochrane Database Syst Rev*. 2001;(1):CD001740. doi:10.1002/14651858. CD001740.

3. Pontoppidan H, Geffin B, Lowenstein E. Acute respiratory failure in the adult: 3. *N Engl J Med*. 1972;287:799-806.

4. Pontoppidan H, Geffin B, Lowenstein E. Acute respiratory failure in the adult: 2. *N Engl J Med*. 1972;287:743-752.

5. Pontoppidan H, Geffin B, Lowenstein E. Acute respiratory failure in the adult: 1. *N Engl J Med*. 1972;287:690-698.

6. Sponsler K, Markly D, Labrin J. What is the appropriate use of antibiotics in AECOPD. *The Hospitalist*. 2012 Jan 26. http://the-hospitalist.org/issue/january-2012.

Suggested Website

1. Society of Critical Care Medicine. http://www.SCCM.org/Guidelines

MECHANICAL VENTILATION

Objectives

- Discuss the indications and techniques for noninvasive positive pressure ventilation.
- Describe the clinical parameters that should be reviewed to decide whether the patient is failing noninvasive methods and requires invasive mechanical ventilation.
- Describe the characteristics of different types of breaths and modes of mechanical ventilation.
- Outline ventilator settings and monitoring needs for the initiation of mechanical ventilation.
- Describe interactions between ventilatory parameters and modifications needed to avoid harmful effects of mechanical ventilation.
- Review the guidelines for initial ventilator management that apply to specific clinical situations.

Case Study

A 67-year-old woman with severe chronic obstructive pulmonary disease presents to the hospital with complaints of an upper respiratory tract illness and increasing shortness of breath of 2 days' duration. She has been using her home nebulizers without relief. Her vital signs are blood pressure 140/90 mm Hg, heart rate 122 beats/min, respirations 32 breaths/min, and temperature 37.2°C (99.0°F). Physical examination is remarkable for use of accessory muscles of respiration and diffuse wheezing bilaterally. She is alert but unable to speak in full sentences. An arterial blood gas analysis demonstrates pH 7.25, P_{CO_2} 62 mm Hg , and P_{O_2} 59 mm Hg. Bronchodilator therapy is

started, and the woman is given IV steroids.

– What type of respiratory support should be initiated?

– What settings should be selected for respiratory support?

– What are the goals of respiratory support?

I. INTRODUCTION

When hypoxic or hypercapnic respiratory failure cannot be treated by other means, as discussed in **Chapter 4**, advanced support with positive pressure ventilation may be needed. A ventilator is a device used to assist or replace the work of the respiratory system. Positive pressure ventilation can be delivered noninvasively via a mask or helmet or invasively via an endotracheal tube. Generally accepted indications for initiating positive pressure ventilatory support are summarized in **Table 5-1**.

Table 5-1	Indications for Positive Pressure Ventilatory Support
Ventilation abnormalities	Respiratory muscle dysfunction • Respiratory muscle fatigue • Chest wall abnormalities • Neuromuscular disease Decreased ventilatory drive Increased airway resistance and/or obstruction
Oxygenation abnormalities	Refractory hypoxemia Need for positive end-expiratory pressure
Work of breathing alterations	Need for decreased work of breathing • Shock • Respiratory muscle fatigue • Severe acidosis
Need for sedation and/or neuromuscular blockade	
Need to decrease systemic or myocardial oxygen consumption	
Use of hyperventilation to reduce intracranial pressure	
Facilitation of alveolar recruitment and prevention of atelectasis	

The choice between noninvasive or invasive positive pressure ventilation is dependent

on patient characteristics, the type and severity of the respiratory and/or systemic condition, anticipated clinical course, availability of resources, and the experience and training of the clinician and healthcare team.

II. NONINVASIVE POSITIVE PRESSURE VENTILATION

A. What is Noninvasive Positive Pressure Ventilation?

Noninvasive positive pressure ventilation (NPPV) refers to a form of mechanical ventilation that provides respiratory assistance without an invasive artificial airway. The potential beneficial effects of NPPV are similar to those of invasive mechanical ventilation and include decreased work of breathing, improved oxygenation, and improved gas exchange. In addition, this type of ventilation avoids many of the complications associated with intubation and invasive mechanical ventilation. Potential advantages and disadvantages of NPPV are listed in **Table 5-2**.

Table 5-2 Advantages and Disadvantages of Noninvasive Positive Pressure Ventilation

Advantages	Disadvantages
• Reduced need for sedation	• Claustrophobia
• Preservation of airway-protective reflexes	• Increased workload for respiratory practitioner
• Avoidance of upper airway trauma	• Facial/nasal pressure lesions
• Decreased incidence of nosocomial sinusitis	• Unprotected airway and pneumonia
• Improved patient comfort	• Inability to suction deep airway
• Shorter length of stay in ICU and hospital	• Gastric distension with use of face mask or helmet
• Improved survival	• Possible upper-extremity edema, axillary vein thrombosis, tympanic membrane dysfunction, and intrahelmet noise with use of helmet
	• Delay in intubation

B. How Does NPPV Work?

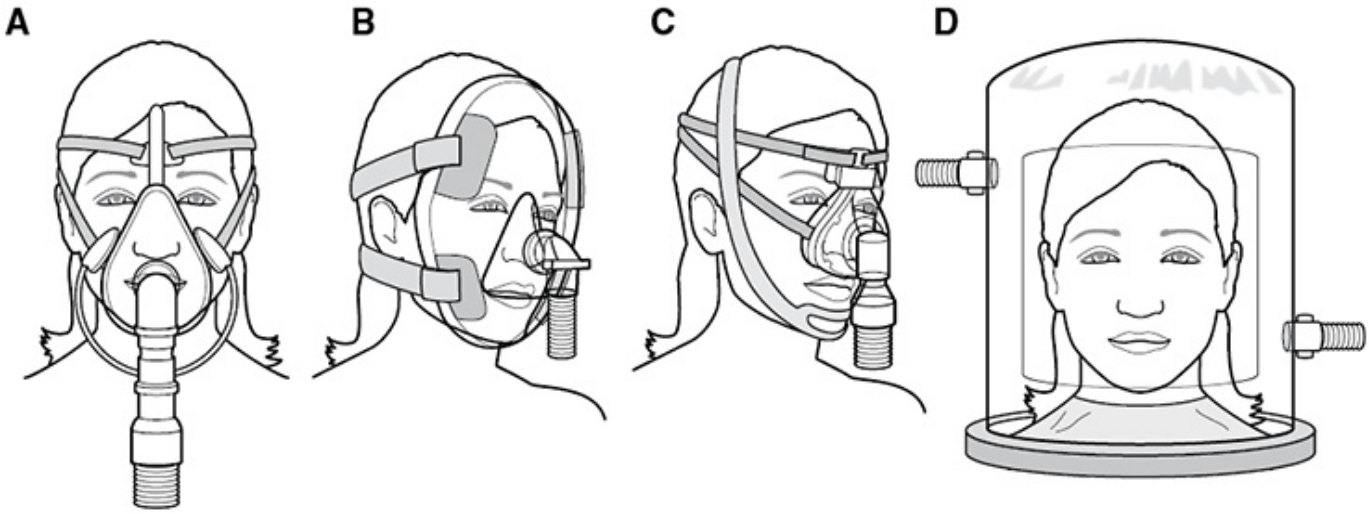
NPPV utilizes two levels of positive airway pressure, combining the modalities of pressure support ventilation (PSV) and continuous positive airway pressure (CPAP)

(discussed later). By convention, the PSV modality is referred to as *IPAP* (inspiratory positive airway pressure), and the CPAP modality is referred to as *EPAP* (expiratory positive airway pressure). CPAP alone can also be delivered noninvasively but does not provide support of ventilation. CPAP allows spontaneous breathing from a gas source at an elevated baseline system pressure (higher than atmospheric pressure) and is functionally equivalent to positive end-expiratory pressure (PEEP). The difference between these two pressure levels (ΔP) determines tidal volume generated. NPPV can be delivered using a standard ICU ventilator or a portable device. The benefits of using an ICU ventilator include delivery of a more precise and higher concentration of oxygen, the separation of inspiratory and expiratory tubing to prevent rebreathing CO_2, better monitoring and alarm features, and improved detection of air leaks. Alarm setups may need to be altered on standard ventilators because the alarms are typically triggered by exhalation, and noninvasive ventilation inherently has more gas leakage compared to ventilation via an endotracheal tube. Ventilators specifically designed to provide patient-triggered noninvasive pressure support or patient-triggered volume-cycled breaths are optimal.

C. What Types of Interfaces Are Available?

The ventilator connects to a tightly fitted face mask, nasal mask, nasal plugs, or a helmet (**Figure 5-1**). Many patients with acute respiratory failure are mouth breathers, so the face mask is preferred as it is associated with smaller leaks than the nasal plugs and nasal mask. The nasal passages may offer significant resistance to airflow, limiting the benefits of NPPV. Some gas leakage is anticipated with both masks and can be compensated for by increasing pressure settings or increasing the set tidal volume (V_T) level. When a nasal mask is used, the patient's mouth should be kept closed or chin straps should be employed to reduce leakage.

Figure 5-1. Devices for Delivery of Noninvasive Positive Pressure Ventilation



Examples of noninvasive positive pressure ventilation delivery devices: **A**, face mask; **B**, total face mask; **C**, nasal mask with chin strap; and **D**, helmet.

D. Which Patients Benefit From NPPV?

Before NPPV is initiated, patient characteristics and the potential for successfully treating the underlying respiratory condition should be evaluated. **Table 5-3** lists conditions leading to respiratory failure that are likely to improve with use of NPPV. Of these, acute exacerbations of chronic obstructive pulmonary disease and cardiogenic pulmonary edema are the two conditions best studied and they have accepted indications for the application of NPPV. An approach to initiating NPPV after appropriate patient evaluation is outlined in **Table 5-4**. NPPV is best utilized in the alert, cooperative patient whose respiratory condition is expected to improve in 48 to 72 hours. Potential candidates should be hemodynamically stable, able to control airway secretions, and able to synchronize with the ventilator. If a provider skilled in the application of NPPV is not available, if the patient is too sick for this support, or if NPPV has failed to benefit the patient, it is critical to move quickly to invasive mechanical ventilation.

Table 5-3	Respiratory Conditions Likely to Respond to Noninvasive Positive Pressure Ventilation
Hypoxemic Respiratory Failure	
• Cardiogenic pulmonary edema without hemodynamic instability • Respiratory failure in patients with mild to moderate *Pneumocystis* pneumonia • Respiratory failure in immunocompromised patients (especially in hematologic malignancies and transplant patients)	

Hypercapnic Respiratory Failure

- Acute exacerbation of chronic obstructive pulmonary disease
- Acute exacerbation of asthma
- Respiratory failure in patients with cystic fibrosis

Table 5-4 Initiation of Noninvasive Positive Pressure Ventilation

- Do not delay intubation if needed and keep in mind the patient's resuscitation status.
- Consider ABG analysis prior to initiation.
- Explain the procedure.
- Keep head of bed at ≥45°.
- Ensure appropriate mask or helmet size.
- Assess the patient's tolerance of the mask by applying it by hand before securing the harness.
- Use the following initial ventilator settings:
  - Mode: Spontaneous
  - Trigger: Maximum sensitivity
  - F_{IO_2}: 1.00
  - EPAP: 4-5 cm H_2O (higher levels are poorly tolerated initially)
  - IPAP: 10-15 cm H_2O
  - Backup rate: Start at 6/min
- Adjust the difference between EPAP and IPAP to achieve and effective V_T and CO_2 clearance. Adjust EPAP for alveolar recruitment in increments of 2 cm H_2O per step to improve oxygenation. Depending on the ventilator, a similar increase in IPAP may be required to maintain the same V_T.
- If assist-control volume ventilation is used, begin with a V_T of 6 to 8 mL/kg (depending on the underlying pulmonary condition).
- Titrate pressures, volume, and F_{IO_2} to achieve appropriate pH, Pa_{O_2}, and Pa_{CO_2} levels. Ventilator changes can be made every 15 to 30 minutes.
- Follow vital signs, pulse oximetry, mental status, clinical appearance, and ABG (if indicated).
- Remember that goals of NPPV may include a respiratory rate <30 breaths/min, V_T >7 mL/kg of predicted body weight, improved gas exchange, and patient comfort.
- It is also important to be cognizant that IPAP > 20 cm H_2O may lead to gastric distension.

Abbreviations: NPPV, noninvasive positive pressure ventilation; ABG, arterial blood gas; EPAP, expiratory positive airway pressure; IPAP, inspiratory positive airway pressure; V_T, tidal volume

E. Which Patients Should Not Receive Noninvasive Mechanical Ventilation?

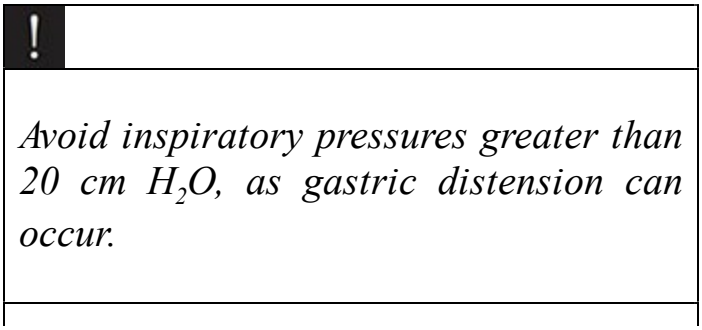
In general, NPPV should not be initiated in the following circumstances: uncooperative patients; patients with difficulty clearing secretions, recurrent emesis, or post-cardiac or respiratory arrest; and patients with hemodynamic instability. A more detailed list of contraindications for the use of NPPV is presented in **Table 5-5**.

Table 5-5	Contraindications to Use of Noninvasive Positive Pressure Ventilation

- Cardiac or respiratory arrest
- Hemodynamic instability
- Myocardial ischemia or arrhythmias
- Patient who is unable to cooperate
- Inability to protect the airway
- High risk for aspiration
- Active upper gastrointestinal hemorrhage
- Severe hypoxemia
- Severe encephalopathy
- Facial trauma, recent surgery, and/or burns
- Significant agitation

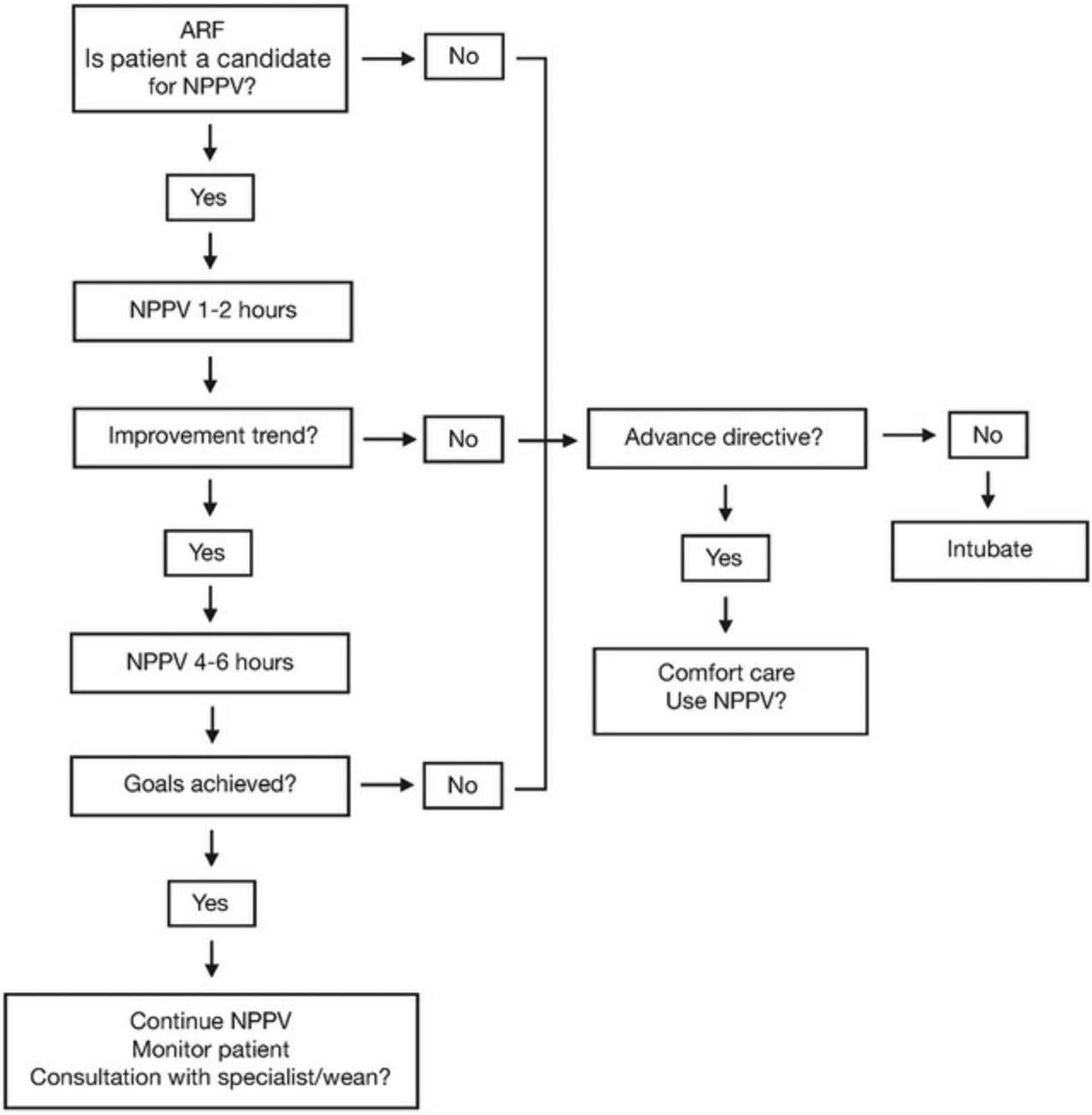
F. How are Patients Monitored on NPPV?

Patients receiving NPPV must be monitored closely in a proper setting, and continuous pulse oximetry and cardiac monitoring are suggested. Close clinical follow-up assessments are required, including evaluations of the pH, Pa_{O_2}, and Pa_{CO_2}. Consider transition to invasive ventilation when a clear trend toward improvement has not been observed over the first 1 or 2 hours, or when the therapeutic goals have not been achieved within the first 4 to 6 hours. Sedation should be used cautiously and with adequate monitoring when NPPV is initiated. Additional measures that may be considered include application of a protective nose patch when using a nasal mask and gastric decompression if a face mask or helmet is used. Oral intake should be restricted until the patient has stabilized and intubation is no longer a consideration. An algorithm for assessing NPPV is presented in **Figure 5-2**.



Avoid inspiratory pressures greater than 20 cm H_2O, as gastric distension can occur.

Figure 5-2. Assessment of Noninvasive Positive Pressure Ventilation



Abbreviations: NPPV, noninvasive positive pressure ventilation; ARF, acute respiratory failure

Case Study (continued)

Noninvasive positive pressure ventilation is initiated. Two hours after initiation, the patient exhibits persistent marked accessory muscle use. Vitals signs are heart rate 130 beats/min, blood pressure 160/90 mm Hg, respiratory rate 32 breaths/min, and temperature 36.6ºC (98°F). Arterial blood gas demonstrates pH 7.27, P_{CO_2} 60 mm Hg, and P_{O_2} 90 mm Hg.

– Should this patient be intubated and invasive mechanical ventilation initiated?

– What are the initial setting on invasive mechanical ventilation?

– How should patients on invasive mechanical ventilation be monitored?

III. DECISION TO INTUBATE

The decision to initiate invasive mechanical ventilation is a crucial and time-sensitive one. Delay in intubation, inability to identify a difficult airway, and inability to anticipate possible hemodynamic consequences of intubation can reduce the likelihood of good patient outcomes. In general, consideration of three quick bedside questions can help facilitate a prompt decision to proceed with invasive mechanical ventilation, especially when transitioning from noninvasive ventilation.

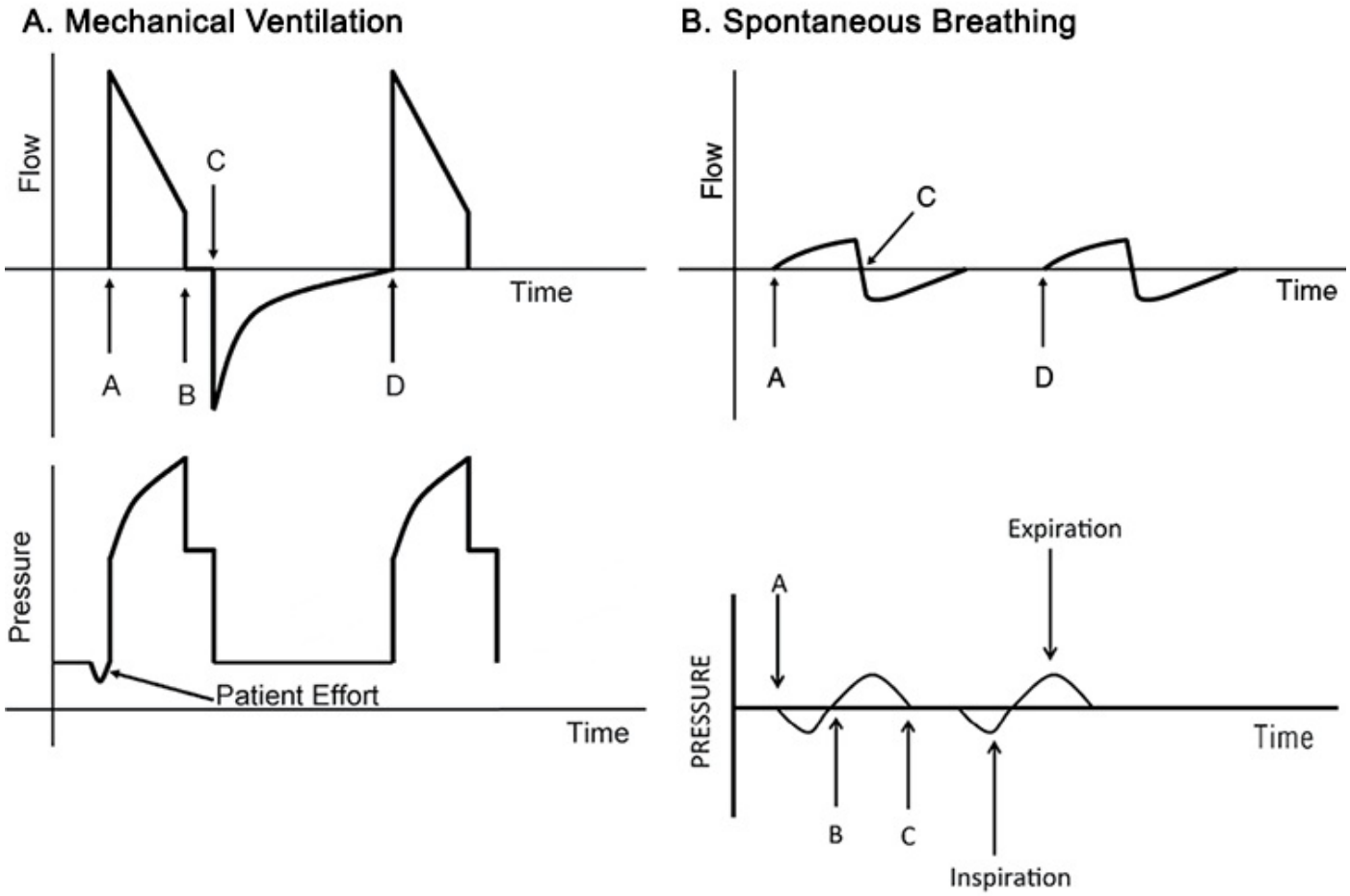
- Is there failure in airway maintenance or protection (eg, inability to handle secretions)?
- Is there failure to achieve desired goals with current respiratory support (oxygenation, ventilation, or work of breathing)?
- Is the illness anticipated to worsen in the next 24 to 48 hours?

IV. INVASIVE MECHANICAL VENTILATION

Mechanical ventilation via an endotracheal tube is commonly used to support critically ill patients. It is a definitive intervention with the goal of obtaining acceptable oxygenation and ventilation with a secure airway.

Each mechanical ventilation respiratory cycle can be divided into two phases: inspiration and expiration (**Figure 5-3A**).

Figure 5-3. Respiratory Cycle During Mechanical Ventilation and Spontaneous Breathing



(Above left) Triggering (**A**) signals the transition from expiration to inspiration; cycling (**C**) indicates the transition from inspiration to expiration. Inspiratory pause (**BC**), total respiratory cycle (**ABCD**), inspiration (**ABC**), and expiration (**CD**).

(Above Right) Start of inspiration (**A**), start of expiration (**B**), inspiration (**AB**), expiration (**BC**), and total respiratory cycle (**ABC**)

The respiratory cycle is the time from the initiation of one breath until the initiation of the next breath. Triggering (**A**) signals the transition from expiration to inspiration; cycling (**C**) indicates the transition from inspiration to expiration. Other components of the total respiratory cycle (**ABCD**) include inspiratory pause (**BC**), inspiration (**ABC**), and expiration (**CD**). Spontaneous breaths do not include an inspiratory pause. The spontaneous respiratory cycle (**ACD**) is demonstrated in **Figure 5-3B**.

Inspiration is the point at which the exhalation valve closes and fresh gas under pressure from the ventilator enters the chest. The amount of gas delivered during inspiration is determined by any of three targets that can be set on the ventilator: volume, pressure, and/or flow.

Cycling is the changeover from the end of inspiration to the expiratory phase. It occurs in response to one of three parameters: elapsed time, delivered volume, or a decrease in

flow rate. During expiration, the ventilator gas flow is stopped, and the exhalation circuit is opened to allow gas to escape passively from the lungs. Expiration continues until the next inspiration begins.

Triggering is the changeover from expiration to inspiration. Triggering a ventilator-delivered breath depends on the patient's interaction with the ventilator:

- *Assisted breath:* The patient initiates a breath, and this inspiratory effort produces a drop in airway pressures or a diversion of constant gas flow in the ventilator circuitry. A signal triggers the ventilator to deliver a breath. This is an example of partial ventilator control.
- *Unassisted, mandatory, or controlled breath*: In the absence of patient interaction with the ventilator, breaths are delivered based on elapsed time (eg, at a set rate of 10 breaths/min and no detection of patient effort, the ventilator will be triggered every 6 seconds). This is an example of full ventilator control.

Spontaneous breaths (no ventilator assistance) are also possible in synchronized intermittent mandatory ventilation (SIMV) and bilevel ventilation. The most common ventilator breaths are described later. CPAP allows spontaneous breathing at a higher baseline pressure.

V. TYPES OF TARGETED/CYCLED BREATHS

A. Volume-Cycled Breath

A volume-cycled breath, often called *volume assist-control breath*, ensures the delivery of a preset tidal volume (unless the peak pressure limit is exceeded). On most ventilators, the setting of peak inspiratory flow rate and the choice of inspiratory flow waveform (square, sine, or decelerating) determine the length of inspiration. Some ventilators change the peak inspiratory flow rate to maintain constant inspiratory time on switching between a constant flow (square) and decelerating flow (ramp) waveforms. With volume-cycled breaths, worsening airway resistance or lung/chest-wall compliance results in increases in peak inspiratory pressure with continued delivery of the set tidal volume (unless the peak pressure limit is exceeded).

B. Time-Cycled Breath

A time-cycled breath, often called *pressure assist-control breath*, applies a constant pressure for a preset time. The application of pressure throughout inspiration results in a square (constant) pressure-over-time waveform during inspiration and a decelerating inspiratory flow waveform as the pressure gradient falls between the ventilator and the patient (since pressure rises as the lung fills). Flow in this breath format is variable and this leads to variable tidal volume depending on lung compliance. Flow depends on the resistance of the lung, the compliance of the lung, and patient effort. With this type of breath, changes in airway resistance or lung/chest-wall compliance will alter tidal volume (ie, worsening of airway resistance or lung compliance results in a decrease in tidal volume).

C. Flow-Cycled Breath

A flow-cycled breath, usually called a *pressure support breath*, is a spontaneous mode of ventilation. The patient initiates every breath and the ventilator delivers support with the preset pressure value. With this support, the patient self-regulates the respiratory rate and tidal volume. The set inspiratory pressure support level is kept constant with a decelerating flow. The patient triggers all breaths. A change in the mechanical properties of the lung/thorax and patient effort affects the delivered tidal volume. The pressure support level must be regulated to obtain the desired ventilation.

Pressure support breaths are terminated when the flow rate decreases to a predetermined percentage of the initial peak flow rate (typically 25%). As the patient's inspiratory effort decreases, the flow decreases, marking the proximity of the end of inspiration.

VI. MODES OF MECHANICAL VENTILATION

The mode of ventilation describes how one or more types of ventilator breaths interface with the patient to provide ventilatory support. When mechanical ventilation is initiated, the optimum ventilatory support for a given clinical circumstance and the specific needs of the patient must be determined. Commonly used modes of ventilation include assist-control (AC) ventilation, SIMV, and PSV. The various modes are achieved by using some combination of the three types of ventilator breaths and may be combined with the application of PEEP.

A. Assist-Control Ventilation

AC ventilation can be delivered with either volume-cycled (volume assist-control) or time-cycled (pressure assist-control) breaths. We will emphasize volume control, since it is the most commonly used mode.

In volume AC, the preset tidal volume (V_T) is guaranteed at a preset flow rate and with a set minimum respiratory rate. The patient can initiate breaths and trigger the ventilator, and the ventilator will assist to achieve the preset V_T delivered at the preset flow. Thus, patients receive the minimum number of ventilator breaths (set rate), but the total number of breaths is higher if the patient triggers the ventilator with additional inspiratory efforts.

With proper use of AC, the work of breathing may be significantly decreased. However, if the ventilator and the patient are not in synchrony or if the ventilator inspiratory flow rates are not matched to the patient's demand, this mode may result in an increase in the patient's work of breathing.

The total number of breaths during AC ventilation may be higher than the minimum set rate, based on the patient's respiratory drive and ability to trigger the ventilator. This mode has also been called continuous mandatory ventilation (CMV). However, CMV more accurately represents a situation in which the patient doesn't trigger additional breaths (ie, absent respiratory drive, as when the patient is paralyzed) [discussed below].

B. Pressure Support Ventilation

PSV provides a preset level of inspiratory pressure assist with each ventilator-detected patient effort. This inspiratory assist is selected to overcome the increased work of breathing imposed by the disease process, endotracheal tube, inspiratory valves, and other mechanical aspects of ventilatory support. The set amount of pressure that is applied augments each patient-triggered breath. All breaths are flow cycled (usually, the assist will decelerate when flow falls <25% of the initial flow rate generated by the patient-initiated breath). The patient controls the respiratory rate and exerts a strong influence on the duration of inspiration, flow rate, and V_T. In addition, the delivered V_T is influenced by pulmonary compliance and resistance. Rapid changes in these parameters potentially alter the V_T and work of breathing. PSV may be coupled with SIMV (see below), primarily as a means to diminish excess work of breathing for spontaneous breaths occurring between mandatory breaths.

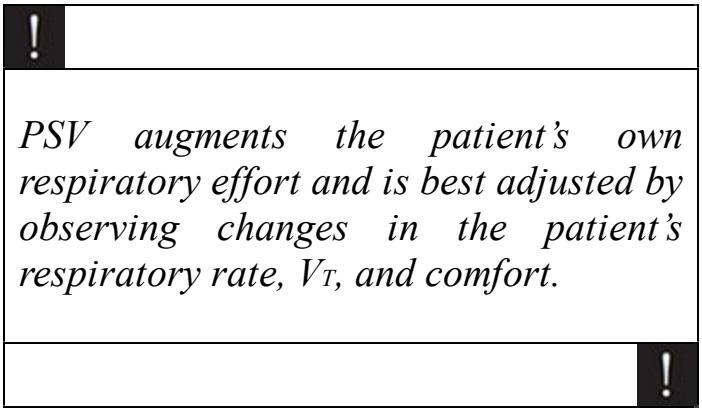
The amount of pressure support is titrated according to the patient's V_T measured by the ventilator during expiration. Suggested parameters include a setting that achieves one or more of the following goals:

- A V_T of 6 to 8 mL/kg, depending on patient needs
- A slowing of spontaneous breathing rate to an acceptable range (<30 breaths/min)
- The desired minute ventilation

Appropriate apnea alarms and a backup ventilation setting are essential. Potential benefits of PSV include the comfort and tolerance this ventilatory mode offers some patients. In addition, PSV may reduce the work of breathing by diminishing patient-ventilator asynchrony. Typically, as pressure support is increased in patients with lung disease, the patient's work of breathing and respiratory rate decrease and V_T increases. With PSV, an endotracheal tube cuff leak may interfere with appropriate cycling because flow may never drop to the preset threshold for cycling (ie, 25% of the peak flow rate).

C. Synchronized Intermittent Mandatory Ventilation

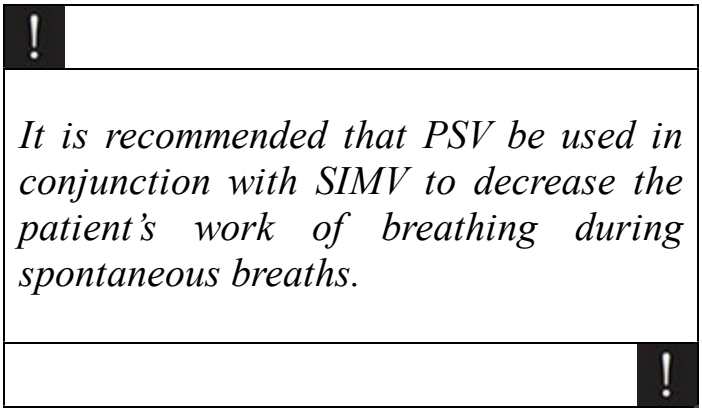
SIMV delivers either volume-cycled or time-cycled breaths at a preset mandatory rate. Volume cycling is most commonly used for the mandatory breaths. Breaths may be triggered by the patient or by the time elapsed. If the patient-initiated breath falls within a certain period of time before the onset of the mandatory breath, the ventilator synchronizes its support by delivering the mandatory breath early, thus essentially converting a controlled breath to an assisted one. The number of breaths that will be synchronized in this fashion is the preset (mandatory) rate. When no effort is detected, the ventilator delivers the preset V_T at the preset (time-elapsed) rate. When the patient initiates breaths over the set mandatory rate spontaneously, these breaths are usually supported by the ventilator (assisted breaths) with the addition of pressure support. Notice the difference from assist control—volume control ventilation, where each breath (patient- or ventilator-initiated) had the same guaranteed V_T.



PSV augments the patient's own respiratory effort and is best adjusted by observing changes in the patient's respiratory rate, V_T, and comfort.

In SIMV, the addition of pressure support to these spontaneous patient-initiated breaths is recommended, using a value that offsets the resistance of the endotracheal tube.

Synchronization allows for enhanced patient-ventilator synchrony by delivering the preset machine breaths in conjunction with the patient's inspiratory effort for each mandatory breath.

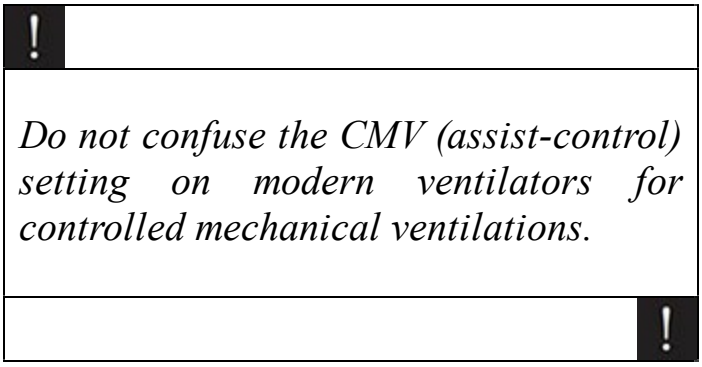


It is recommended that PSV be used in conjunction with SIMV to decrease the patient's work of breathing during spontaneous breaths.

The SIMV mode allows patients to contribute to and determine a portion of their ventilatory requirement. The negative inspiratory pressure generated by spontaneous breathing may lead to increased venous return to the right side of the heart, which may improve cardiac output and cardiovascular function. When no pressure support is added, potential increases in work of breathing may delay weaning from mechanical ventilation.

D. Controlled Mechanical Ventilation

CMV delivers unassisted ventilator breaths at a preset rate. All breaths are mandatory and are either volume cycled or time cycled. No additional spontaneous assisted breaths are initiated beyond the set number of controlled breaths. Current ventilators do not allow direct setting of CMV, and this mode can be achieved only in patients who are not capable of spontaneous respiratory effort, such as those who are heavily sedated or receiving neuromuscular blockade.



Do not confuse the CMV (assist-control) setting on modern ventilators for controlled mechanical ventilations.

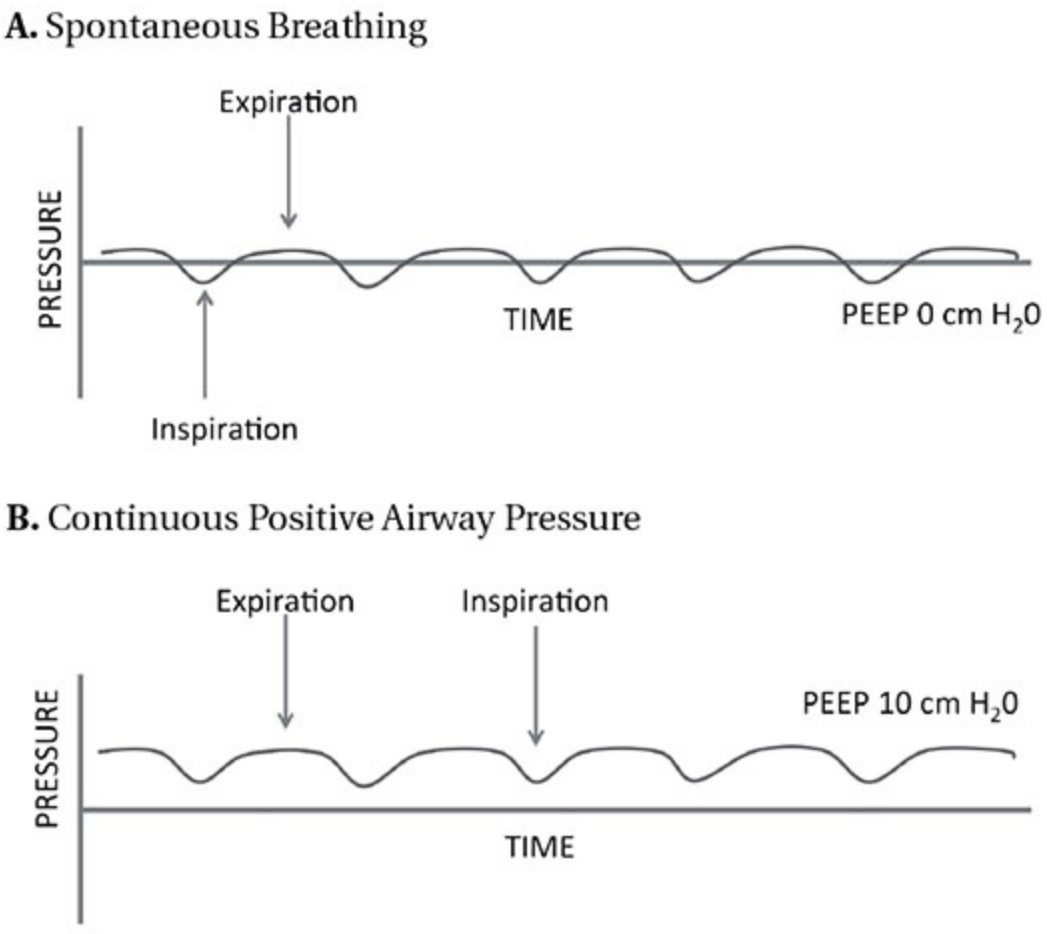
E. CPAP And Weaning

CPAP is seldom used as initial support for acute respiratory failure in an intubated patient and is not considered a mode of mechanical ventilation. Here continuous positive pressure is applied throughout the respiratory cycle with the patient breathing spontaneously around the applied pressure. Therefore, respiratory rate and V_T depend entirely on the patient's inspiratory effort (without help from the ventilator) as the patient inspires against the resistance of the endotracheal tube. CPAP with low levels of pressure support (typically 5-7 cm of water) may be used for weaning during the final stages of invasive ventilation when patients are being assessed for their potential readiness for extubation.

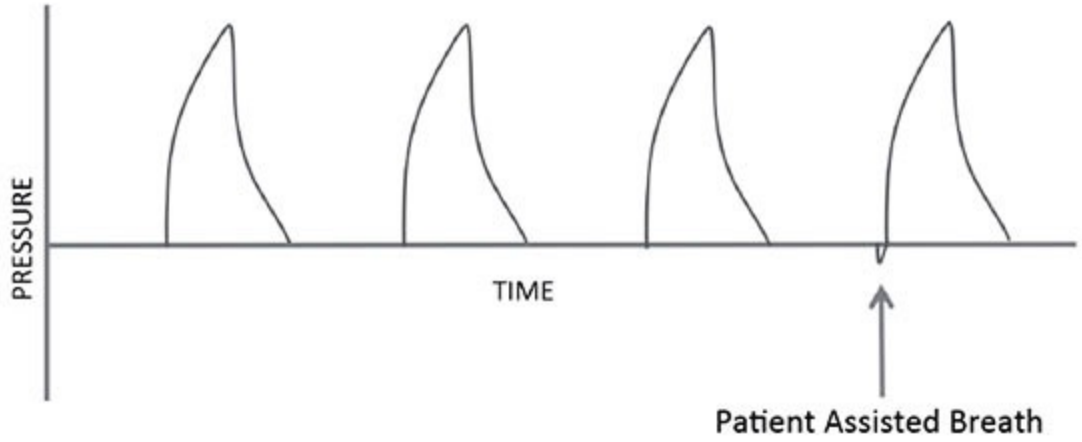
Airway pressure and flow tracings of spontaneous respiration, CPAP, and the different modes of mechanical ventilation are illustrated in **Figure 5-4**.

Figure 5-4. Airway Pressure and Flow Tracings

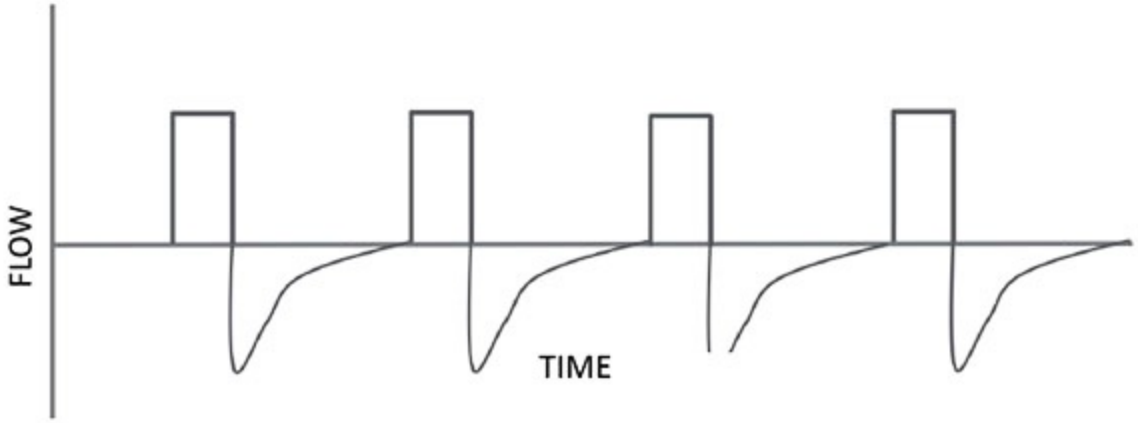
Figure 5-4. Airway Pressure and Flow Tracings



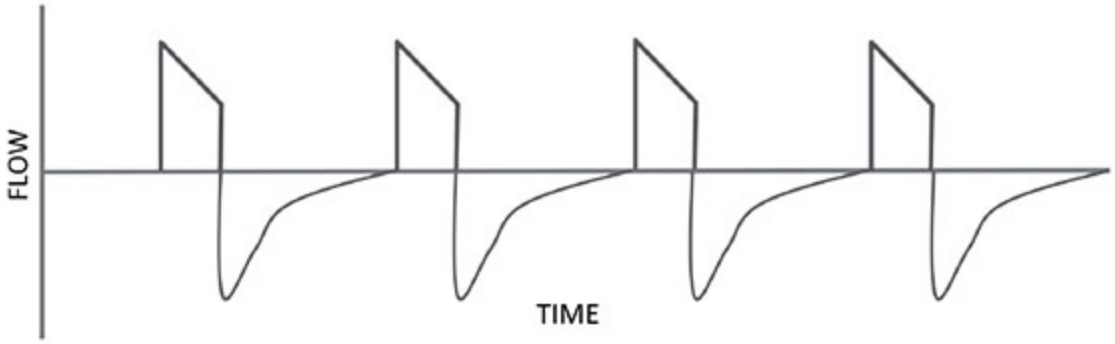
C. Volume Assist Control – Pressure Time Waveform



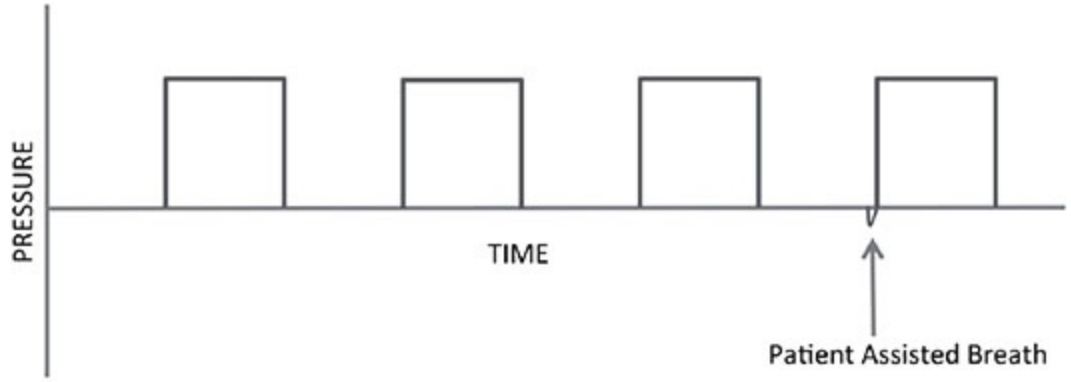
D. Volume Assist Control – Flow Time Waveform (Square Constant Flow)



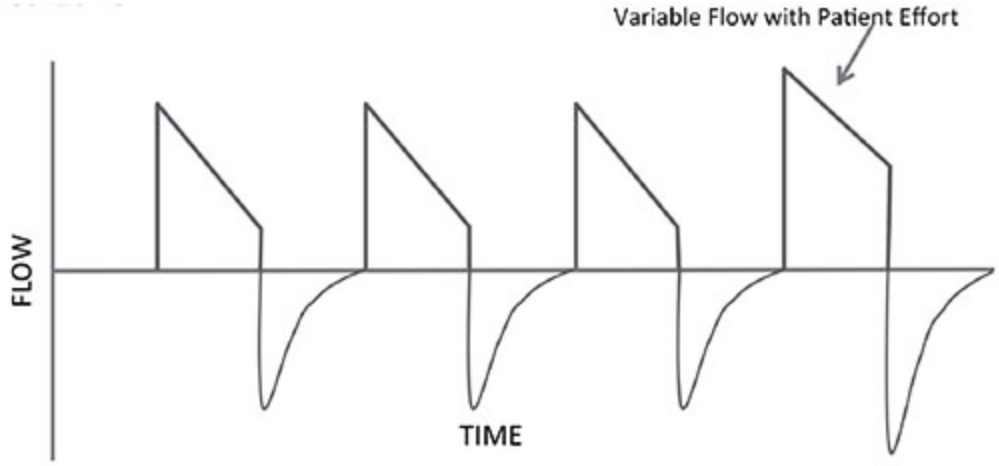
E. Volume Assist Control – Flow Time Waveform (Decelerating Constant Flow)



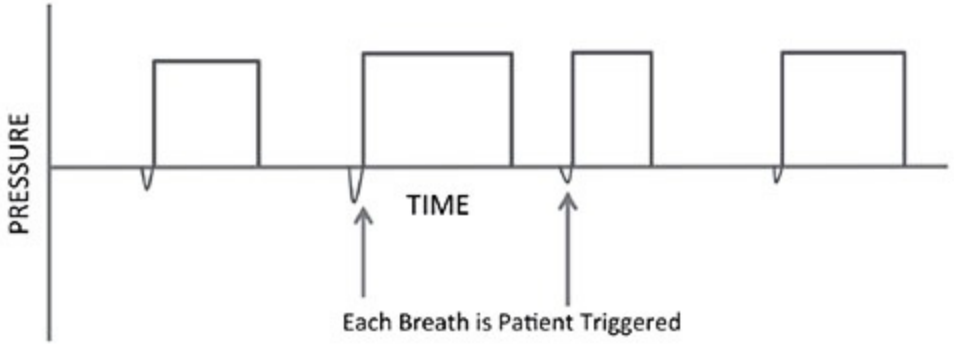
F. Pressure Assist Control Ventilation – Pressure Time Waveform



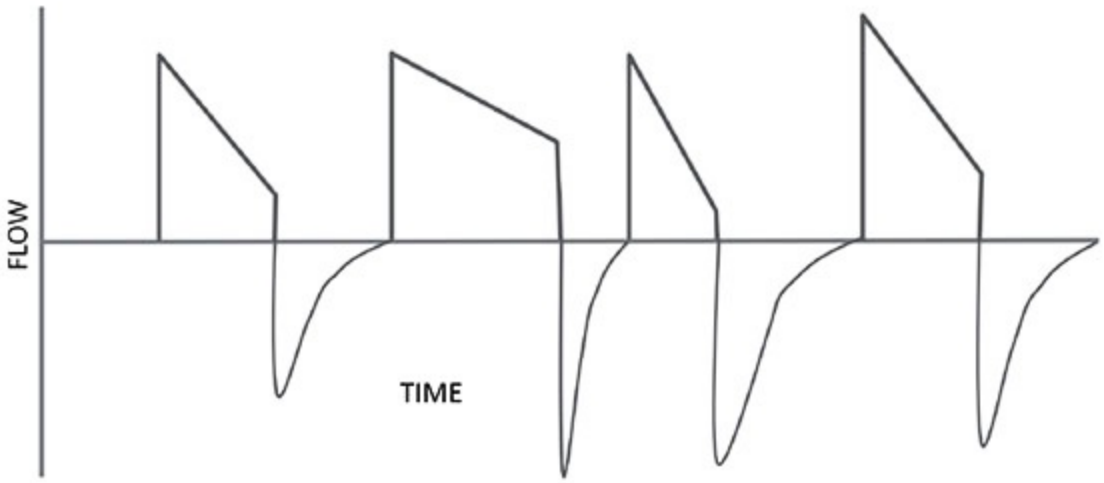
G. Pressure Assist Control Ventilation – Flow Time Waveform



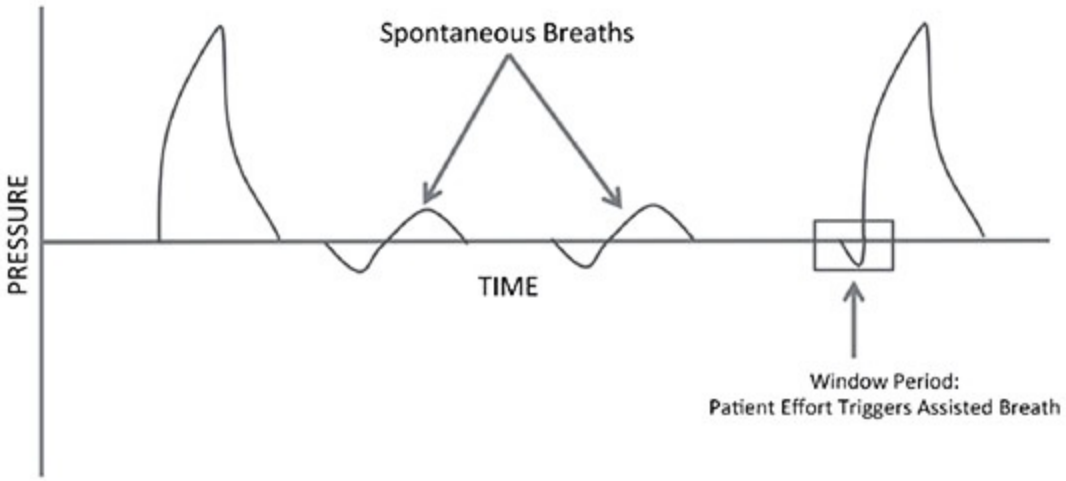
H. Pressure Support Ventilation – Pressure Time Waveform



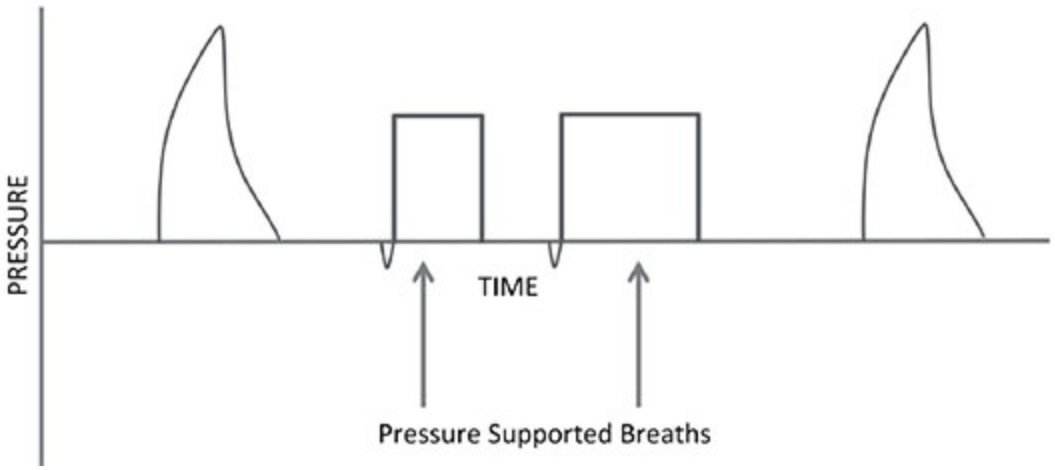
I. Pressure Support Ventilation – Flow Time Waveform



J. SIMV without Pressure Support– Pressure Time Waveform



K. SIMV with Pressure Support – Pressure Time Waveform



The advantages and disadvantages of the various modes of invasive mechanical

ventilation are summarized in **Table 5-6**. In choosing a mode of ventilation, it is important to consider specific goals, the most important of which are adequacy of ventilation and oxygenation, reduction in the work of breathing, and the assurance of patient comfort and synchrony with the ventilator.

Table 5-6 Potential Advantages and Disadvantages of Selected Modes of Mechanical Ventilation

Mode	Advantages	Disadvantages
AC ventilation	Patient can increase ventilatory support; reduced work of breathing compared with spontaneous breathing	Excessive inspiratory pressures
AC volume ventilation	Guarantees delivery of set V_T (unless peak pressure limit is exceeded)	Excessive inspiratory pressures
AC pressure ventilation	Limitation of peak inspiratory AC pressure ventilation pressures; variable flow rates accommodate to patients' demands	V_T decreases or increases with lung resistance/compliance changes
Pressure support ventilation	Apnea alarm may not trigger backup ventilation mode; variable patient tolerance	Patient comfort; improved patient-ventilator interaction; decreased work of breathing
Synchronized intermittent mandatory ventilation	Less interference with normal cardiovascular function	Increased work of breathing compared with AC
Controlled mechanical ventilation	Rests muscles of respiration completely	Requires use of sedation/neuromuscular blockade; adverse hemodynamic effects

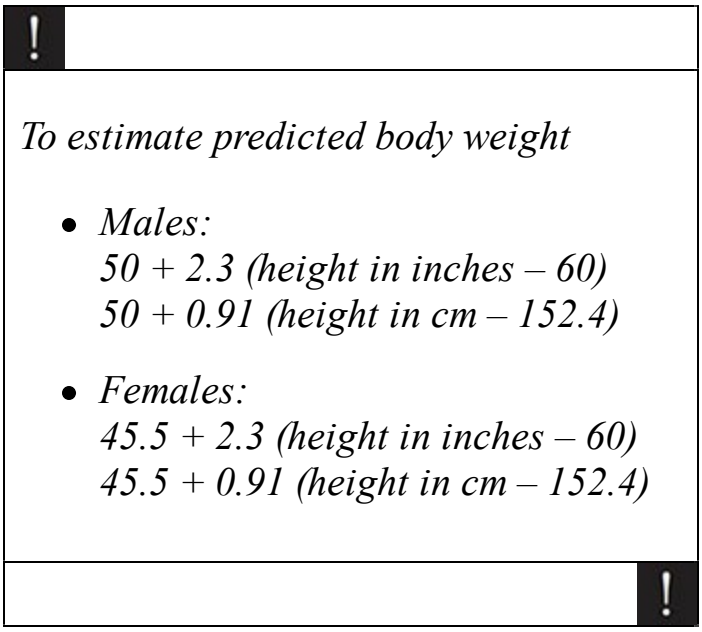
Abbreviations: AC, assist-control; V_T, tidal volume

VII. CHOOSING A MODE AND INITIAL VENTILATOR SETTINGS

Choosing a mode of mechanical ventilation depends on the reason it is required and the underlying disease process. In general, AC is used as the initial mode for a patient needing invasive mechanical ventilation.

When initiating ventilatory support in adults, a fraction of inspired oxygen (F_{IO_2}) of 1.0 is used to ensure maximal amount of available oxygen during the patient's adjustment to the ventilator and during the initial attempts to stabilize the patient's condition. In addition, the high level of oxygen offers support for complications that may have occurred before and during intubation. The usual recommended V_T level is 6 to 8 mL/kg

of the predicted body weight. Higher V_T levels should be avoided to reduce the possibility of lung injury. An appropriate respiratory rate should be set to achieve the desired minute ventilation. Normal minute ventilation (V_T × respiratory rate) is approximately 7 to 8 L/min, but certain conditions may require levels that more than double this baseline. Minute ventilation should be adjusted to produce the Pa_{CO_2} level that allows an acceptable acid-base (pH) status for the patient's clinical condition. As a general rule, F_{IO_2}, mean airway pressure, and PEEP affect the Pa_{O_2}, whereas the respiratory rate, dead space (V_D), and V_T affect alveolar minute ventilation and Pa_{CO_2}.



To estimate predicted body weight

- *Males:*
  50 + 2.3 (height in inches – 60)
  50 + 0.91 (height in cm – 152.4)
- *Females:*
  45.5 + 2.3 (height in inches – 60)
  45.5 + 0.91 (height in cm – 152.4)

Although a normal or close to normal acid-base (pH) status may allow resumption of optimal functioning of the cellular metabolism essential to the recovery of a critically ill patient, in some circumstances (acute respiratory distress syndrome and severe obstructive lung disease), the goals of mechanical ventilation are not to normalize blood gases. Hypercapnia and respiratory acidosis are tolerated in such situations to achieve goals such as minimizing dynamic hyperinflation and avoiding ventilator-associated lung injury. Hence, individual ventilator settings and their titration contribute to a dynamic process that must be tailored to the patient's changing needs. Guidelines for the initiation of mechanical ventilation are listed in **Table 5-7**.

Table 5-7 Guidelines for the Initiation of Mechanical Ventilation

1. Choose the ventilator mode with which you are most familiar. The primary goals of ventilatory support are adequate oxygenation/ventilation, reduced work of breathing, synchrony between patient and ventilator, and avoidance of high end-inspiration alveolar pressures.
2. The initial F_{IO_2} should be 1.0. The F_{IO_2} thereafter can be titrated downward to maintain the Sp_{O_2} at 92% to 94%. In severe acute respiratory distress syndrome, Sp_{O_2} ≥88% may be acceptable to minimize

complications of mechanical ventilation.

3. Initial V_T = 8 to 10 mL/kg in patients with relatively normal lung compliance. In patients with poor lung compliance (eg, ARDS), a target V_T of 6 mL/kg by PBW is recommended to avoid overdistension and maintain an inspiratory plateau pressure ≤30 cm H_2O.
4. Choose a respiratory rate and minute ventilation appropriate for the particular clinical requirements. Target pH, not Pa_{CO_2}.
5. Use PEEP in diffuse lung injury to maintain an open alveoli at end expiration. If volume is held constant, PEEP may increase peak inspiratory plateau pressure, a potentially undesirable effect in ARDS. PEEP levels >15 cm H_2O are rarely necessary
6. Set the trigger sensitivity to allow minimal patient effort to initiate inspiration. Beware of auto cycling if the trigger setting is too sensitive.
7. In patients at risk of obstructive airway disease, avoid choosing ventilator settings that limit expiratory time and cause or worsen auto-PEEP.
8. Call the critical care consultant or other appropriate consultant for assistance.

Abbreviations: V_T, tidal volume; Spo_2, oxyhemoglobin saturation as measured by pulse oximetry; ARDS, acute respiratory distress syndrome; PBW, predicted body weight; PEEP, positive end-expiratory pressure

VIII. CONTINUING CARE DURING MECHANICAL VENTILATION

After mechanical ventilation has been initiated, the following parameters should be assessed and titrated to achieve the desired goals. Many important interrelationships exist among ventilator settings, and the consequences of making any change must be appreciated. This interdependency of parameters may lead to beneficial or harmful effects in the respiratory and/or cardiovascular systems. Critical care consultation should be obtained for continuing ventilator management.

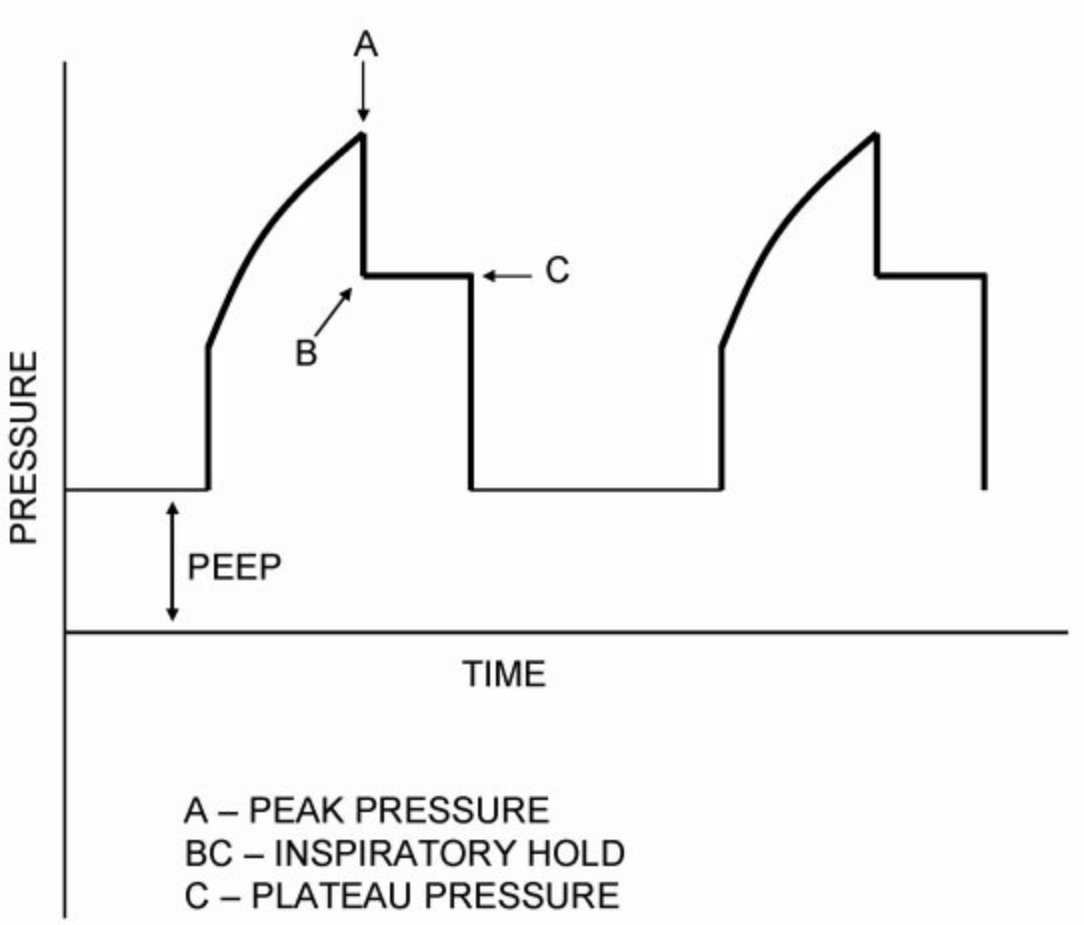
A. Inspiratory Pressures

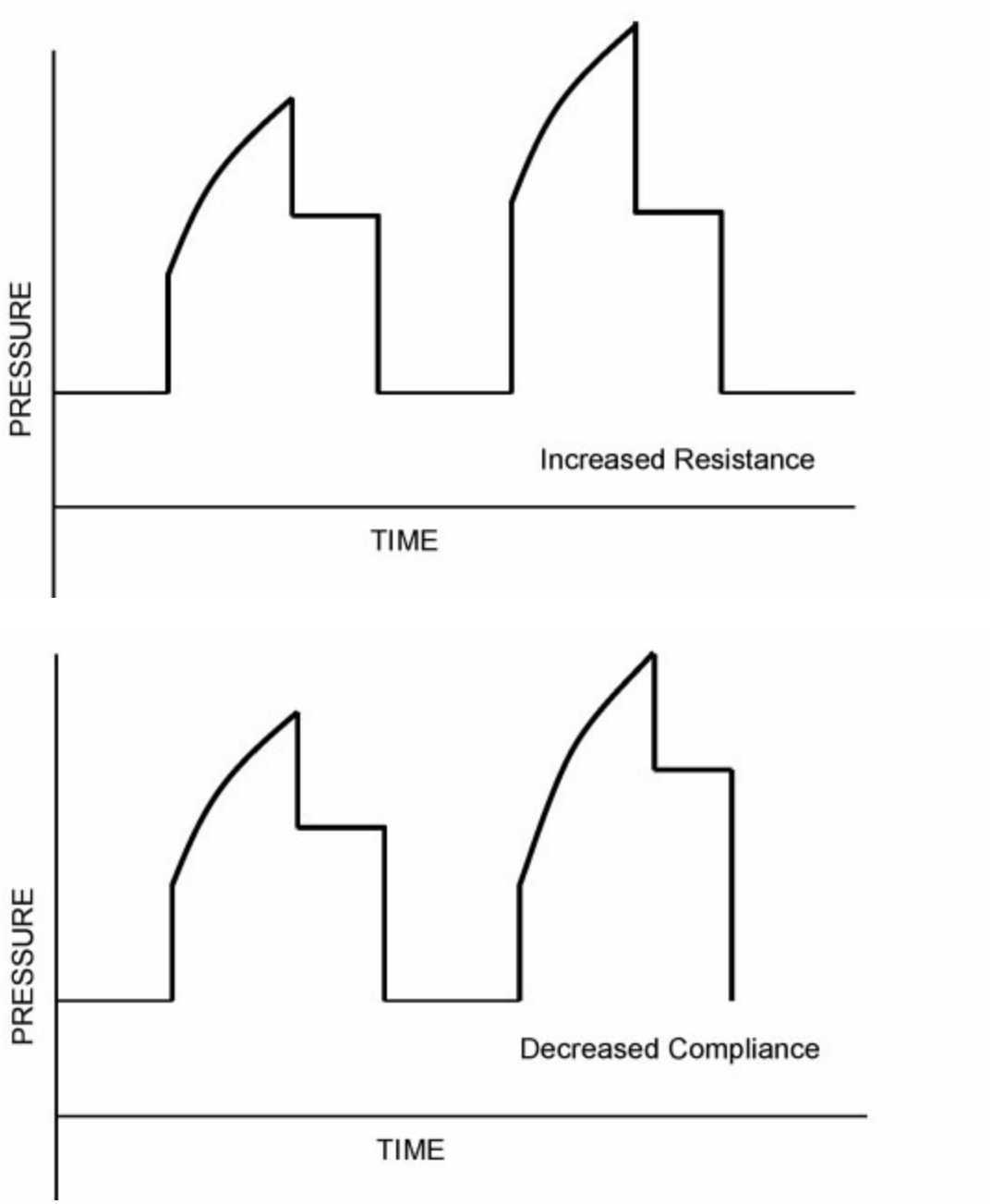
During positive pressure volume assist-control ventilation, airway pressure rises progressively to a peak inspiratory pressure (Ppeak; **Figure 5-5**), which is reached at end inspiration. The Ppeak is the sum of the pressure required to overcome airway resistance and the pressure required to overcome the elastic properties of the lung and chest wall. Ppeak, sometimes referred to as *peak airway pressure*, is affected by many other variables, such as the flow rate, diameter of the endotracheal tube, secretions, and diminished bronchial diameter. When an inspiratory hold is applied at the end of inspiration, gas flow ceases, all dynamic factors are eliminated, and the pressure drops to a measurement called the *inspiratory plateau pressure* (Pplat). The Pplat reflects the pressure required to overcome the elastic recoil within the lung and chest wall and, contrary to the Ppeak, is a static pressure. The Pplat is the best estimate of peak alveolar pressure, which is an important indicator of alveolar distension. Accurate

measurement of Pplat requires the absence of any patient effort and an inspiratory hold for a minimum of 0.5 seconds (usually 1 second).

Potential adverse effects from high inspiratory pressures include barotrauma, volutrauma, and reduced cardiac output. Barotrauma (pneumothorax, pneumomediastinum) and volutrauma (lung parenchymal injury due to overinflation), although linked to high Ppeak, correlate best with Pplat. The relation of Ppeak and Pplat is illustrated in **Figure 5-5**. This figure demonstrates airway pressure tracings for typical volume assist-control ventilation under conditions of normal compliance and resistance, increased airway resistance, and decreased respiratory system compliance.

Figure 5-5. Relationship of Peak Inspiratory Pressure and Inspiratory Plateau Pressure





Abbreviation: PEEP, positive end-expiratory pressure

As mentioned earlier, an example of the relationship of Ppeak and Pplat to alveolar distension is demonstrated by the effect of endotracheal tube size on Ppeak and Pplat. As the internal diameter of an endotracheal tube is decreased in a patient receiving (fixed volume) ventilation, the same V_T will result in higher Ppeak, yet Pplat (obtained during inspiratory hold) and alveolar distension remain unchanged as the pressure is dissipated across the resistance of the endotracheal tube. The same V_T, regardless of the type of breath, produces the same alveolar distension at end inspiration. To avoid injury in patients receiving mechanical ventilation, Pplat should be maintained <30 cm H_2O. When compliance is decreased, both Ppeak and Pplat rise for a fixed V_T. As resistance is unchanged, the difference between peak pressure and plateau pressure is not affected.

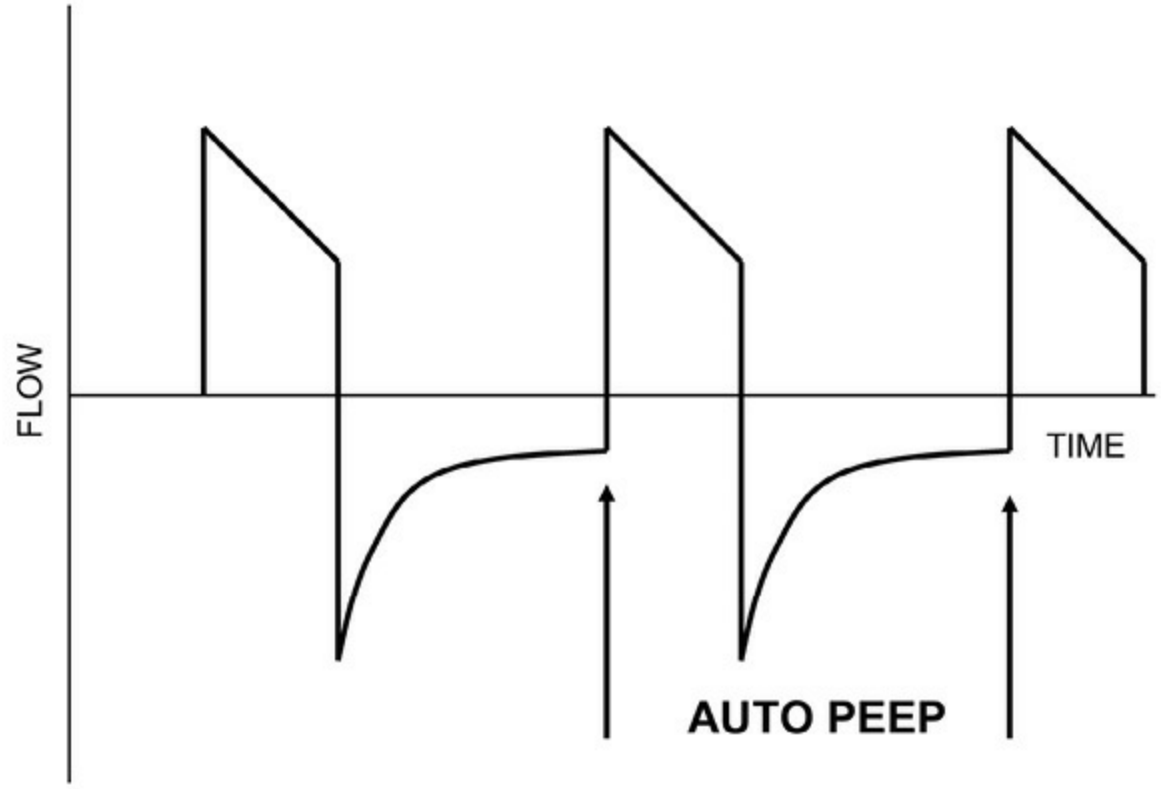
Elevated Pplat may be reduced by the following interventions:

- Decrease PEEP, which may also decrease oxygenation and worsen alveolar collapse (if PEEP is used to improve oxygenation and alveolar stability).
- Decrease V_T, which may lead to hypercapnia due to a reduction in minute ventilation.
- Avoid and decrease auto-PEEP (see below) with interventions that prolong the expiratory time, understanding that this may lead to hypercapnia.

B. Relation of Inspiratory Time to Expiratory Time and Auto-PEEP

If the expiratory time is too short to allow full exhalation, the previously delivered breath is not completely expired and the next lung inflation is superimposed upon the residual gas in the lung. This results in lung hyperinflation and PEEP above the preset level on the ventilator. This increase in end-expiratory pressure is called *auto-PEEP*, or *intrinsic*, *inadvertent*, or *occult PEEP*. Auto-PEEP can be quantified by using manual methods or through electronic programs within some ventilators during an expiratory hold maneuver. However, it is most easily diagnosed qualitatively by viewing the flow-versus-time graphic waveform tracing available on most mechanical ventilators, as the expiratory flow fails to reach the zero flow level before the initiation of the next breath (**Figure 5-6**). The potentially harmful physiologic effects of auto-PEEP on peak, plateau, and mean airway pressures are the same as those of preset PEEP. In addition, high levels of PEEP may decrease venous return to the heart, resulting in hypotension and higher P_{CO_2} due to increased dead space, and adversely affect oxygenation (especially with asymmetric lung disease).

Figure 5-6. Flow-Time Waveform Demonstrating Auto-PEEP



Abbreviation: PEEP, positive end-expiratory pressure

Auto-PEEP may be reduced by the following interventions:

- Decrease respiratory rate by changing the set rate or sedating the patient. These interventions result in fewer inspirations per minute and thus increase the total expiratory time available; this is the most effective way of decreasing auto-PEEP.
- Decrease V_T, which requires less time to deliver a smaller breath and allows more time for exhalation.
- Increase gas flow rate, delivering the V_T faster and allowing more time in the cycle for exhalation. This intervention has little impact unless the initial flow rate was set at an extremely low level. It will also lead to an increase in the airway pressure.
- Change the inspiratory waveform from decelerating (ramp) to constant (square), which delivers V_T in a shorter time, allowing more time for exhalation.

As discussed earlier, the first two interventions may lead to hypercapnia due to a reduction in minute ventilation; however, the benefits of a decrease in auto-PEEP despite the lower minute ventilation may lead to little change in $Paco_2$. When severe air trapping occurs, allowing sufficient expiratory time may improve ventilation and CO_2

removal. Hypercapnia and a controlled reduction in pH (permissive hypercapnia) may be acceptable in some clinical conditions but requires expert consultation. This approach may not be suitable for patients with intracranial hypertension because hypercapnia causes cerebral vasodilation and further increases in the intracranial pressure.

C. F_{IO_2}

High levels of inspired oxygen may be harmful to lung parenchyma after prolonged exposure. Although the precise threshold for concern is not known, it is desirable to reduce the F_{IO_2} ≤0.5 (50% oxygen) within the first 24 hours. However, hypoxemia is always considered a greater risk to the patient than high F_{IO_2} levels. The primary determinants of oxygenation during mechanical ventilation are F_{IO_2} and mean airway pressure. Other minor determinants include V_T, inspiratory-expiratory ratio, inspiratory flow rate, PEEP, auto-PEEP, use of inspiratory pause, and the inspiratory flow waveform pattern (volume breaths). In the patient with acute respiratory distress syndrome (ARDS), PEEP becomes a major determinant of mean airway pressure. The interrelationships of these various parameters, as already demonstrated, often lead to complex adjustments within the mechanical ventilation plan.

D. Minute Ventilation and Alveolar Minute Ventilation

Minute ventilation, defined as the amount of gas exchanged by an individual in 1 minute, is calculated as the respiratory rate multiplied by mean V_T. The primary determinant of CO_2 exchange during mechanical ventilation is the alveolar minute ventilation, calculated as:

$$VA = (V_T - V_D)f$$

where V_D is dead space and f is the respiratory rate (**Chapter 4**). The V_T, the respiratory rate, and their interrelationships with other ventilatory parameters have already been discussed. Physiologic V_D represents, in general, lung units that are relatively well ventilated but under-perfused. The physiologic effect of high amounts of V_D is hypercapnia (impaired CO_2 clearance). Dead space may result from the pathologic process in the lung or from mechanical ventilation complicated by high airway pressures, low intravascular volume, or low cardiac output.

As previously discussed, adequate ventilation is assessed by consideration of both the Pa_{CO_2} and the pH. Hyperventilation resulting in a low Pa_{CO_2} level may be an appropriate

short-term compensatory goal during metabolic acidosis while the primary etiology is corrected. Similarly, a patient with chronic hypercapnia has an increased baseline Pa_{CO_2} and maintains a near-normal pH by renal compensation (increased bicarbonate retention). Patients with chronic compensated hypercapnia should receive sufficient minute ventilation during mechanical ventilation to maintain the Pa_{CO_2} at their usual (baseline) level, and utmost attention should be paid to the pH to avoid severe alkalemia and loss of retained bicarbonate.

E. Humidification

Gases delivered by mechanical ventilators are typically dry, and the upper respiratory tract is bypassed by artificial airways, resulting in loss of heat and moisture. Heating and humidification of gases are routinely provided during mechanical ventilation to prevent mucosal damage and minimize inspissation of secretions. Available systems include passive humidifiers (artificial nose) or active, microprocessor-controlled heat and humidifying systems (heated humidifiers). The passive humidifiers are contraindicated in the presence of copious secretions, minute ventilation >12 L/min, air leaks >15% of delivered tidal volume, or blood in the airway.

F. Use of Positive End-Expiratory Pressure

Adjustment of PEEP is the cornerstone strategy employed for disease states that cause alveolar collapse or airway closure (eg, ARDS). It causes alveolar recruitment and prevents repeated opening and closing of the alveoli (atelectrauma). Titration of PEEP for hypoxemic respiratory failure secondary to ARDS can be performed according to the PEEP/F_{IO_2} combinations given in **Table 5-8**.

Table 5-8	Suggested Combinations of PEEP and F_{IO_2} to Reach Goal Pa_{O_2}								
F_{IO_2}	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.7
PEEP (cm H_2O)	5-14	5-14	8-16	8-16	10-20	10-20	10-20	12-20	14-20
F_{IO_2}	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.0	
PEEP (cm H_2O)	14-22	14-22	14-22	16-22	18-22	20-22	22	24	

Abbreviations: PEEP, positive end-expiratory pressure; F_{IO_2}, fraction of inspired oxygen

In cases of severe obstructive lung disease, applying external PEEP and setting it close to the auto-PEEP value can help offset the work of breathing to trigger the ventilator. Seeking expert consultation is prudent if higher levels of PEEP are required to maintain

oxygenation.

G. Prophylactic Therapies

Mechanical intubation is a risk factor for venous thromboembolism, gastric stress ulceration, and nosocomial pneumonia. Measures to prevent venous thromboembolism include the prophylactic use of anticoagulation (unless contraindicated) and/or pneumatic compression devices. Using a proton pump inhibitor or histamine 2-receptor blocker is warranted for stress ulcer prevention. The risk of ventilator-associated pneumonia (ventilator bundle) is reduced by elevation of the head of the bed to ≥30°, oral hygiene, and daily evaluations for liberation from mechanical ventilation.

IX. SEDATION, ANALGESIA, AND NEUROMUSCULAR BLOCKADE

Endotracheal intubation and mechanical ventilation can be uncomfortable and anxiety provoking. To improve the patient's comfort and synchrony with the ventilator, anxiolytics, sedatives, and analgesics may be administered. Neuromuscular blocking agents should be used with caution, and expert consultation should be sought before initiation. Guidelines for the use of these agents are outlined in the Society of Critical Care Medicine's *Clinical Practice Guidelines for Sustained Neuromuscular Blockade in the Adult Critically Ill Patient* and in *Clinical Practice Guidelines for the Management of Pain, Agitation, and Delirium in Adult Patients in the Intensive Care Unit*. Caution also should be exercised with use of sedation in nonintubated patients with acute respiratory insufficiency or impending respiratory failure.

X. VENTILATORY GUIDELINES FOR SPECIFIC CLINICAL SITUATIONS

Case Study

A 36-year-old previously healthy man presents to the hospital with complaints of a cough, sputum production, and fever of 2 days' duration. Admission chest radiograph reveals a developing infiltrate in the left lower lobe. The man is admitted to the general

ward and started on antibiotics for community-acquired pneumonia. Less than 24 hours later, the patient continues to deteriorate and requires oxygen, 10 L/min. He is not in obvious respiratory distress; however, pulse oximetry reveals severe hypoxemia (83% to 89% on supplemental oxygen, 10 L/min.) Sputum cultures show *Streptococcus pyogenes* (group A) colonies, and a new chest radiograph reveals new, diffuse bilateral alveolar infiltrates. The patient is intubated due to worsening hypoxemia.

– What initial ventilator settings would you use for this patient?

– What steps should be taken to minimize barotrauma during ventilation?

– What parameters should be measured and monitored?

A. Acute Respiratory Distress Syndrome

ARDS causes a decrease in lung compliance, making the lungs stiff and difficult to inflate, and produces hypoxemic respiratory failure (**Chapter 4**). Guidelines for mechanical ventilation in ARDS are outlined in **Tables 5-8** and **5-9**. High Ppeak and Pplat complicate mechanical ventilation because of the low lung compliance or high airway resistance. Lower V_T (4-6 mL/kg of predicted body weight) is required, and the Pplat should be maintained at the desired level of ≤30 cm H_2O; permissive hypercapnia may be required to accomplish that goal. The F_{IO_2} is increased as necessary to prevent hypoxemia but reduced as soon as other ventilatory interventions are effective. Because of increased shunt in ARDS, hypoxemia may be severe. PEEP is the most effective way to improve oxygenation and is typically applied in the range of 8 to 15 cm H_2O, based on the severity of hypoxemia. Higher PEEP levels may be indicated in severe lung injury. Although patients with ARDS are somewhat less likely to develop auto-PEEP because expiratory time requirements are reduced due to decreased lung compliance (stiffness), its presence should be monitored, especially at higher inspiratory-expiratory ratios. **Table 5-9** outlines the recommended strategy for ventilating patients with ARDS. **Table 5-8** outlines the recommended F_{IO_2} and PEEP combinations.

Table 5-9	Mechanical Ventilation in Acute Respiratory Distress Syndrome

Goals

- Pa_{O_2}: 55-80 mm Hg (7.3-10.7 kPa)
- Pplat: ≤30 cm H_2O
- V_T: 4-6 mL/kg PBW
- pH: >7.15 is acceptable

Start with Assist-Control with V_T of 8 mL/kg PBW

- Decrease by 1 mL/kg over the next 4 hours until V_T of 4-6 mL/kg is reached.
- If Pplat is >30 cm H_2O, decrease V_T by 1 mL/kg until V_T is 4 mL/kg or arterial pH reaches 7.15.
- If using V_T of 4 mL/kg and Pplat is <25 cm H_2O, V_T can be increased by 1 mL/kg until Pplat is 25 cm H_2O or V_T is 6 mL/kg.
- If a Pplat of ≤30 cm H_2O has been achieved with a V_T >6 mL/kg and a lower V_T is clinically problematic (ie, need for increased sedation), it is acceptable to maintain the higher V_T.

Initiation of PEEP in Acute Respiratory Distress Syndrome

- Initiate PEEP at 5 cm H_2O and titrate up in increments of 2-3 cm H_2O (**Table 5-8**).
- Full recruitment effect may not be apparent for several hours.
- Monitor blood pressure, heart rate, and Pa_{O_2} or pulse oximetry during PEEP titration and at intervals while the patient is receiving PEEP therapy.
- Optimal PEEP settings are typically 8-15 cm H_2O.

NOTE: These guidelines are summarized to facilitate early intervention in critical patients. The physician should be familiar with these situations and seek appropriate consultation as soon as possible.

Abbreviations: Pplat, plateau pressure; V_T, tidal volume; PBW, predicted body weight; PEEP, positive end-expiratory pressure

Case Study

A 28-year-old woman with a history of asthma is intubated and admitted to the ICU for an acute asthma exacerbation. Peak airway pressure on admission was 40 cm H_2O, and Pplat was 25 cm H_2O immediately after intubation; however, 6 hours later, peak airway pressures have arisen to 55 cm H_2O while the Pplat has remained the same.

– What is the likely etiology of her high peak airway pressures in the setting of unchanged plateau pressures?

– What adjunctive therapies, in addition to ventilator support, does this patient need to reduce the elevated airway pressures?

– Which parameter (ie, peak airway pressure or Pplat) has been associated with a higher risk of barotrauma in an intubated patient?

B. Obstructive Airway Disease

Mechanical ventilation for patients with asthma and chronic obstructive pulmonary disease is designed to support oxygenation and assist ventilation until airway obstruction has improved. After initial intubation, airway secretions and persistent small airway obstruction may manifest as elevated peak airway pressures and a normal Pplat. This suggests an airway obstruction (not worsening compliance), and bronchodilators and steroids should be used aggressively to help alleviate this obstruction while mechanical ventilation supports the patient. As airflow improves, the patient will tolerate higher V_T levels and longer inspiratory times.

Mechanical ventilation in these patients may also produce hyperinflation, auto-PEEP, and resultant hypotension. Therefore, careful attention is needed to balance cycle, inspiratory, and expiratory times. The initial V_T should be 6 to 8 mL/kg, and the minute ventilation should be adjusted to a low normal pH. With volume ventilation, the inspiratory flow rate should be set to optimize the inspiratory-expiratory ratio and allow complete exhalation. Such management reduces breath stacking and the potential for auto-PEEP.

C. Asymmetric Lung Disease

Asymmetric lung disease or injury that occurs after aspiration, contusion, or a localized pneumonia may cause abnormal distribution of ventilation and gas exchange during mechanical ventilation. Because the conditioned gas from the ventilator follows the path of least resistance along the bronchi, the V_T is distributed primarily to the less-affected (more-compliant) lung and may overexpand it. Overdistension of the less-affected lung and poor expansion of the diseased/injured lung worsen ventilation-perfusion relationships in both lungs, and hypoxemia and hypercapnia may occur, persist, or worsen, in addition to causing injury to the normal lung. Standard settings and principles of ventilator support should be initiated. However, if this is unsuccessful, expert consultation should be obtained to facilitate further efforts at patient management. Putting the less-involved lung in the gravitationally dependent (decubitus) position may be helpful in directing pulmonary blood flow to lung units receiving better ventilation. Other techniques, such as differential lung ventilation, could be considered, and immediate expert consultation may be required.

D. Heart Disease

The major goals of ventilatory support in patients with myocardial ischemia are to decrease the work of breathing and ensure adequate oxygen delivery to the heart. Decreasing the work of breathing will reduce the consumption of oxygen by respiratory

muscles, thus increasing oxygen availability to the heart. Patients with cardiogenic pulmonary edema who are mechanically ventilated receive additional benefit from the decrease in preload as a result of increased intrathoracic pressure. Left ventricular afterload also decreases through application of positive juxtacardiac pressure during systole.

E. Neuromuscular Disease

Patients with peripheral neuromuscular disease typically have an intact respiratory drive and normal lungs. These patients may require a higher V_T level to avoid the sensation of dyspnea. Adjustments are made in other ventilatory parameters to ensure a normal arterial pH.

XI. MONITORING MECHANICAL VENTILATORY SUPPORT

Patients who receive mechanical ventilatory support require continuous monitoring to assess the beneficial and potential adverse effects of treatment (**Table 5-10**). Arterial blood gas measurements provide valuable information about the adequacy of oxygenation, ventilation, and acid-base balance. This information is essential during the initial phases of ventilatory support and during periods of patient instability. If available, a pulse oximeter (**Chapter 6**) and end-tidal capnometer (for measuring end-tidal CO_2) can be used to further monitor the patient's progress.

Table 5-10 Recommendations for Monitoring Mechanical Ventilatory Support

- Obtain a chest radiograph after intubation and repeat as indicated to evaluate any deterioration in status.
- Obtain arterial blood gas measurements after initiation of mechanical ventilation and intermittently based on patient status.
- Measure vital signs frequently and observe the patient directly (including patient-ventilator interaction).
- Measure inspiratory plateau pressure as clinically appropriate.
- Use pulse oximetry to monitor oxygenation.
- Use ventilator alarms to monitor key physiologic and ventilator parameters.

Ventilators are equipped with sophisticated alarms and monitors to assist with patient management and detection of adverse events. When initiating ventilatory support, the respiratory care practitioner usually establishes alarm parameters for low and high minute ventilation, high inspiratory pressures, and low exhaled volumes and pressures. Many ventilators allow for the measurement of auto-PEEP.

The low-pressure alarm is intended to alert the clinician to a leak in the circuit or to ventilator disconnection. A high-pressure alarm warns that the set maximum peak airway pressure has been exceeded; this alarm is usually set 10 cm H_2O above the patient's baseline peak airway pressure. If a patient receiving volume ventilation develops mucous plugging or a marked change in airway resistance or lung compliance, the peak pressure will rise acutely. If the peak pressure alarm sounds with volume ventilation, it implies that the patient is not receiving the set V_T, as inspiration ends when the pressure alarm limit is exceeded. Conversely, in pressure preset modes of ventilation, changes in airway resistance or lung compliance will trigger the low exhaled volume alarm.

XII. HYPOTENSION ASSOCIATED WITH INITIATION OF MECHANICAL VENTILATION

A. Tension Pneumothorax

When hypotension occurs immediately after initiation of mechanical ventilation, tension pneumothorax should be one of the first considerations. This diagnosis is based on a physical examination that finds decreased or absent breath sounds and tympany to percussion on the side of the pneumothorax. Tracheal deviation away from the side of the pneumothorax may be observed, although it is uncommon after placement of an endotracheal tube. Treatment includes emergent decompression by inserting a large-bore catheter or needle into the second or third intercostal space in the midclavicular line. Treatment should not be delayed awaiting a chest radiograph. The insertion of a catheter or needle is both diagnostic and therapeutic: it improves blood pressure and reverses the findings of physical examination. The insertion of the catheter or needle must be followed by chest tube placement.

B. Conversion from Negative to Positive Intrathoracic Pressure

Normal intrathoracic pressure is slightly negative relative to the atmosphere. When positive pressure ventilation is initiated, intrathoracic pressure becomes positive. As intrathoracic pressure rises, right atrial pressure rises and the intravascular pressure gradient for return of blood from the large extrathoracic veins into the right heart decreases. As a result, blood return to the heart may be reduced. Left ventricular preload, stroke volume, cardiac output, and blood pressure then may decrease in sequence. Underlying intravascular volume depletion exacerbates the deleterious effects

of the increased intrathoracic pressure on cardiac output and blood pressure. Treatment of this common complication includes volume resuscitation by means of rapidly infused fluid boluses to raise extrathoracic venous pressure and increase venous return to the right heart until the blood pressure increases. Oxygen saturation should be monitored to avoid overly aggressive fluid resuscitation. Use of ventilation techniques associated with high mean airway pressure may exacerbate the deleterious hemodynamic consequences of mechanical ventilation.

C. Auto-PEEP

As previously discussed, auto-PEEP occurs when the combination of ventilator settings and patient physiology results in an inadequate expiratory time. Excessive end-expiratory pressure may increase intrathoracic pressure and cause hypotension due to decreased venous return to the heart. Although auto-PEEP may occur in any patient, those with obstructive airway disease are particularly predisposed to this condition because of the need for a prolonged expiratory phase.

D. Acute Myocardial Ischemia/Infarction

Stress from the cause of acute respiratory failure, as well as the stress of intubation itself, may lead to increased myocardial oxygen demand and to acute myocardial ischemia, infarction, and subsequent hypotension. Patients at high risk should be evaluated with serial electrocardiograms and myocardial markers of injury.

Key Points

Mechanical Ventilation

- The primary goals of noninvasive and invasive positive pressure ventilation are to support ventilation and oxygenation, and to reduce work of breathing while ensuring patient comfort.
- NPPV is best utilized in the alert, cooperative patient whose respiratory condition is expected to improve in 48 to 72 hours.
- The advantages and disadvantages of the different modes of invasive mechanical ventilation must be considered when determining the optimal ventilatory support

for the patient's clinical condition.

- Guidelines for initiating mechanical ventilation should be carefully followed, with adjustments made based on patient assessment and monitoring.
- The complex interactions of inspiratory pressures, inspiratory-expiratory ratio, F_{IO_2}, and PEEP must be appreciated to evaluate the potential benefits and harmful effects in each patient.
- The primary determinants of oxygenation are F_{IO_2} and mean airway pressure, whereas alveolar ventilation primarily affects CO_2 exchange.
- During mechanical ventilation, a patient must be closely monitored using the ventilator alarm systems, continuous pulse oximetry, attentive physical assessment, measurement of inspiratory Pplat (as clinically appropriate), and intermittent arterial blood gases and chest radiographs as needed.
- High inspiratory plateau pressures are associated with a higher incidence of ventilator-induced lung injury and should be maintained below 30 cm H_2O.
- Hypotension occurring immediately after initiation of invasive mechanical ventilation should prompt evaluation for tension pneumothorax, decreased venous blood return due to intrathoracic pressure, auto-PEEP, or myocardial ischemia.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Acute Respiratory Distress Syndrome Network. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. *N Engl J Med*. 2000;342:1301-1308.
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Suggested Website

1. Society of Critical Care Medicine/Guidelines. www.SCCM.org.

MONITORING OXYGEN BALANCE AND ACID-BASE STATUS

Objectives

- Outline the determinants of oxygen balance.
- Recognize disorders of oxygen delivery.
- Identify the principles and limitations of techniques for monitoring oxygen balance.
- Explain the use of acid-base status in monitoring the seriously ill patient.

Case Study

A 67-year-old woman was admitted to the hospital 3 days ago with abdominal pain, fever, and general malaise. She was found to have acute cholecystitis and underwent a laparoscopic cholecystectomy 1 day ago. Today she developed shortness of breath and altered mental status. Her abdominal exam is benign except for mild tenderness at the trocar sites. The patient's pulse is 136 beats/min, blood pressure 106/55 mm Hg, respiratory rate 28 breaths/min and oxygen saturation on pulse oximetry (Spo_2) 94% while breathing room air.

– What monitoring should be immediately implemented?

– What additional parameters should be assessed to determine if the oxygen balance is adequate?

I. INTRODUCTION

Monitoring is never therapeutic, and information from monitoring tools must be

integrated with patient assessment and clinical judgment to determine optimal care. In addition, the clinician must be aware of the limitations and risk-benefit ratio of a monitoring system. Monitoring may be as simple as measuring the pulse or temperature or as complex as invasive hemodynamic techniques with direct and calculated measurements. More invasive monitoring strategies that carry a higher risk should be considered if they provide sufficient new information to guide therapy. As an example, neuroendocrine responses to physiological stress lead to early effects on heart rate, respiratory rate, vascular tone, and blood pressure. Abnormalities of these combined signs may suggest the need for more intensive monitoring to appropriately evaluate and treat the patient. This chapter will emphasize basic monitoring techniques that can be accomplished in most care environments.

The goals of monitoring in seriously ill patients are to recognize physiological abnormalities and to guide interventions to ensure adequate blood flow and oxygen delivery for maintenance of cellular and organ function. Tissue oxygenation cannot be directly measured or monitored, but estimates of the adequacy of oxygenation can be made based on knowledge of the oxygen balance, which is determined by oxygen delivery and oxygen consumption. An understanding of these principles is required to appreciate the usefulness and limitations of various monitoring tools.

II. PRINCIPLES OF OXYGEN DELIVERY

Oxygen delivery is the amount of oxygen presented to the tissues, and it is the component of oxygen balance that can more often be altered by interventions in the seriously ill patient. Normally, the amount of oxygen delivered to the tissues is three to four times greater than the tissue needs. In critical illness, physiologic derangements that result in an absolute decrease in the oxygen delivered or an increase in tissue oxygen demand may compromise this margin of safety. In addition, sufficient oxygen delivery does not always guarantee adequate oxygen utilization at the tissue level. Oxygen delivery is dependent on cardiac output (blood flow) and the oxygen content of arterial blood. Invasive and/or more complex noninvasive monitoring is required for exact measurement of cardiac output. However, an understanding of the variables that determine oxygen content in the blood and cardiac output, along with less invasive monitoring, may guide appropriate treatment.

A. Oxygen Content of Arterial Blood

Arterial oxygen content (Ca_{O_2}) is defined as the amount of oxygen bound to hemoglobin

plus the amount of oxygen dissolved in arterial blood. The components of arterial oxygen content are related by the formula:

$$Ca_{O_2}\ (mL\ O_2/dL) = [Hemoglobin\ (g/dL) \times 1.34 \times Sa_{O_2}\ (\%)] + [0.0031 \times Pa_{O_2}\ (mm\ Hg)]$$

where Sa_{O_2} is the arterial oxyhemoglobin saturation and Pa_{O_2} is the partial pressure of oxygen in arterial blood. Each fully saturated gram of hemoglobin transports 1.34 to 1.39 mL of oxygen, depending on the affinity of hemoglobin for oxygen. Hemoglobin is the major contributor of oxygen for tissue demands and releases bound oxygen based on cellular uptake of dissolved oxygen as blood flows through the capillaries. The ability of hemoglobin to release more oxygen when supply is inadequate or cellular demand is increased is one of the main compensatory mechanisms to sustain cellular function. The oxyhemoglobin dissociation curve shows the relationship of hemoglobin saturation and P_{O_2} (**Figure 6-1**). When the P_{O_2} drops to approximately 40 mm Hg (5.3 kappa) in the capillaries, the decrease in oxyhemoglobin saturation to 75% reflects the amount of oxygen released to the tissues. During physiological stress, oxyhemoglobin saturation at the tissue level may decrease to <20%, reflecting the release of additional oxygen to tissues. Acidosis and fever will shift this curve to the right, resulting in a lower affinity of oxygen for hemoglobin and greater delivery of oxygen to the tissues.

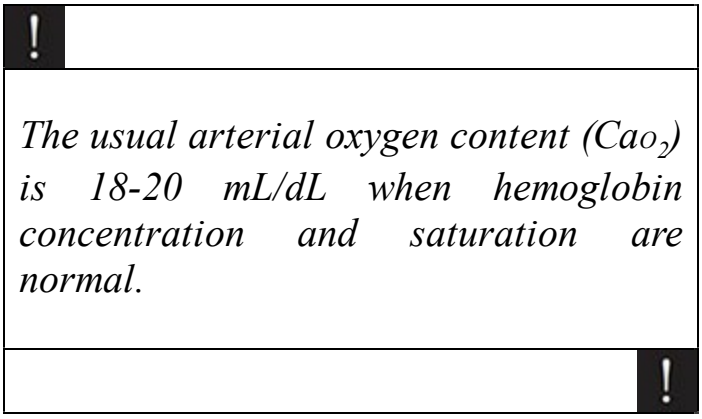
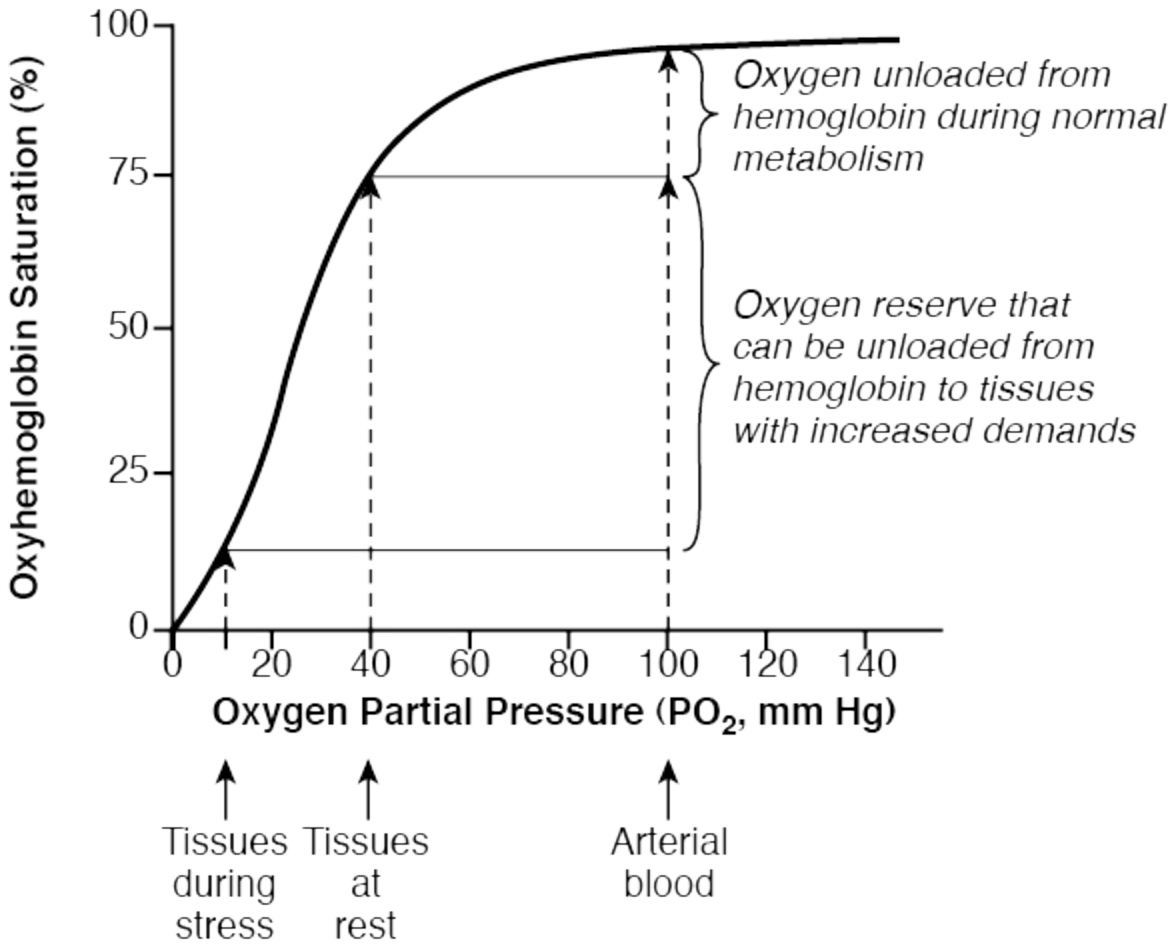
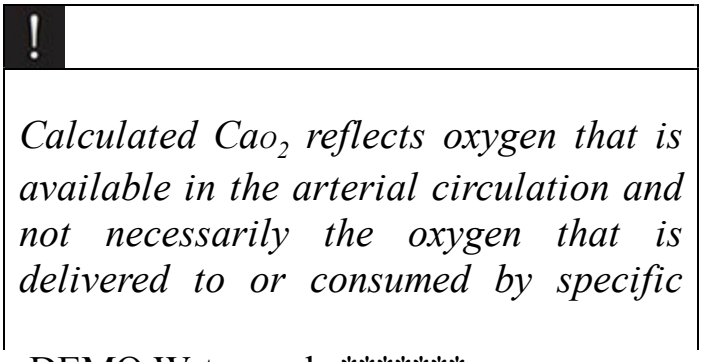


Figure 6-1. Oxyhemoglobin Dissociation Curve



The oxyhemoglobin dissociation curve relates the Po_2 to oxyhemoglobin saturation. Near-maximal saturation of hemoglobin occurs at a Po_2 of 60 mm Hg (8.0 kPa). Po_2 values above this point provide only a modest increase in oxyhemoglobin saturation. Note, however, that a rapid decrease in oxyhemoglobin saturation occurs when the Po_2 drops below 60 mm Hg (8.0 kPa).

Arterial oxygen content can be estimated by using the direct measurement of the hemoglobin concentration and arterial oxyhemoglobin saturation in intermittent blood samples, as dissolved oxygen ($0.0031 \times Pa_{O_2}$) contributes minimally to oxygen content. Although hemoglobin is not monitored continuously, oxyhemoglobin saturation measured by pulse oximetry (Sp_{O_2}) allows continuous assessment of this determinant of arterial oxygen content.



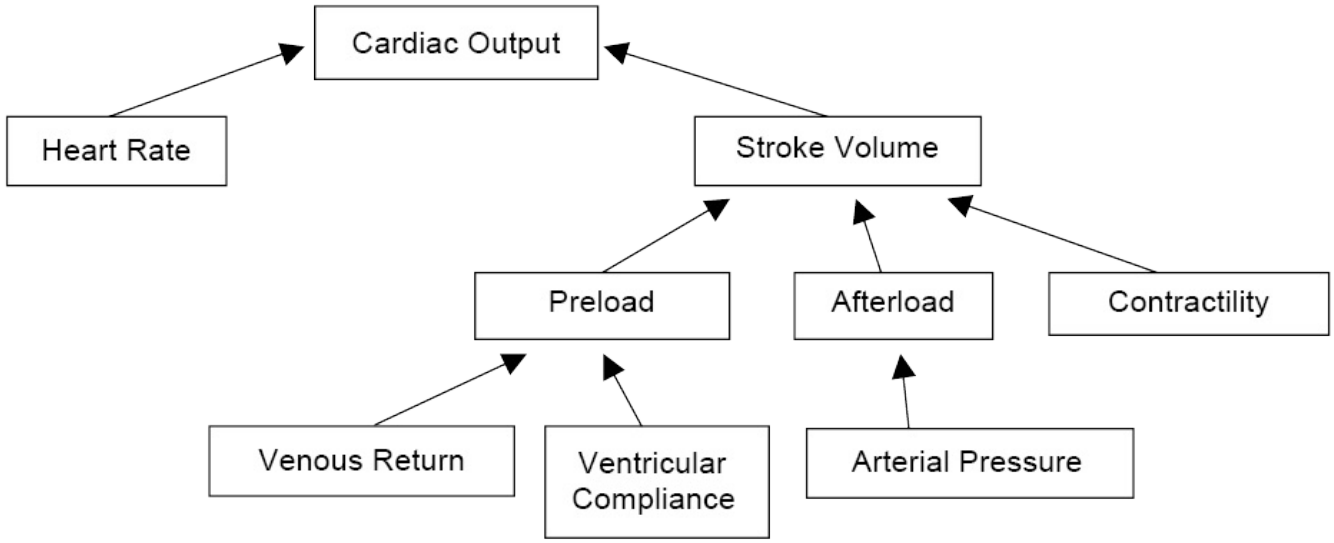
Calculated Ca_{O_2} reflects oxygen that is available in the arterial circulation and not necessarily the oxygen that is delivered to or consumed by specific

tissues.

B. Cardiac Output

If the oxygen content of arterial blood is optimum, then an appropriate cardiac output is needed to ensure delivery of oxygen to the tissues. Cardiac output (in mL/min or L/min) is the product of heart rate and stroke volume (**Figure 6-2**). Stroke volume is the quantity of blood pumped out of the left heart with each beat and is determined by the difference between the end-diastolic volume and end-systolic volume of the ventricle. Variables that determine stroke volume are preload, afterload, and contractile function. The first compensatory mechanism to increase oxygen delivery is often an increase in heart rate. Patients who are unable to increase their heart rate (eg, beta-blockade or fixed pacing) will have a limited ability to compensate.

Figure 6-2. Cardiac Output as the Product of Heart Rate and Stroke Volume



Although the heart rate is easily measured and evaluated, an evaluation of stroke volume requires special noninvasive, minimally invasive, or invasive methods. The option of measuring cardiac output by assessing stroke volume depends on the training, expertise, and resources available. The pulmonary artery catheter is infrequently used as an invasive method of measuring intermittent or continuous cardiac output but requires critical care expertise. Minimally invasive hemodynamic methods measure cardiac output using analysis of the arterial waveform or aortic blood flow. Devices that analyze the arterial waveform to determine pulse pressure, stroke volume, and cardiac

output require an arterial catheter, and some also require a central venous catheter. Esophageal Doppler devices estimate cardiac output from measurement of blood flow in the descending aorta. Noninvasive hemodynamic monitors use principles of bioimpedance or bioreactance to determine stroke volume and cardiac output. The clinician must be aware of the limitations that affect measurement accuracy and interpretation of any chosen technique. If cardiac output is not directly measured, an indirect assessment of variables involved in determining cardiac output (**Table 6-1**) and knowledge of hemodynamic principles can be useful.

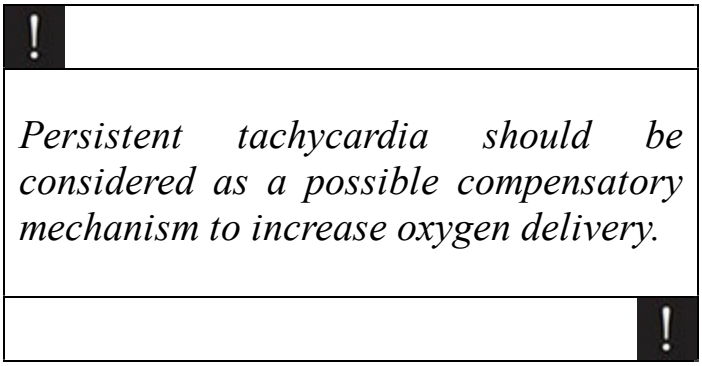


Table 6-1	Clinical Assessment of Determinants of Cardiac Output
Variable	**Method of Assessment**
Heart rate and rhythm	Finger on pulse Pulse oximetry Electrocardiography
Preload	
Right heart	Neck vein distension, liver enlargement, dependent edema Central venous pressure
Left heart	Presence of dyspnea of exertion, orthopnea Pulmonary edema, rales on lung examination
Afterload (left heart)	Mean arterial blood pressure
Contractility	Ejection fraction and stroke volume estimate by echocardiography*

*Requires special training and expertise

1. Contractility

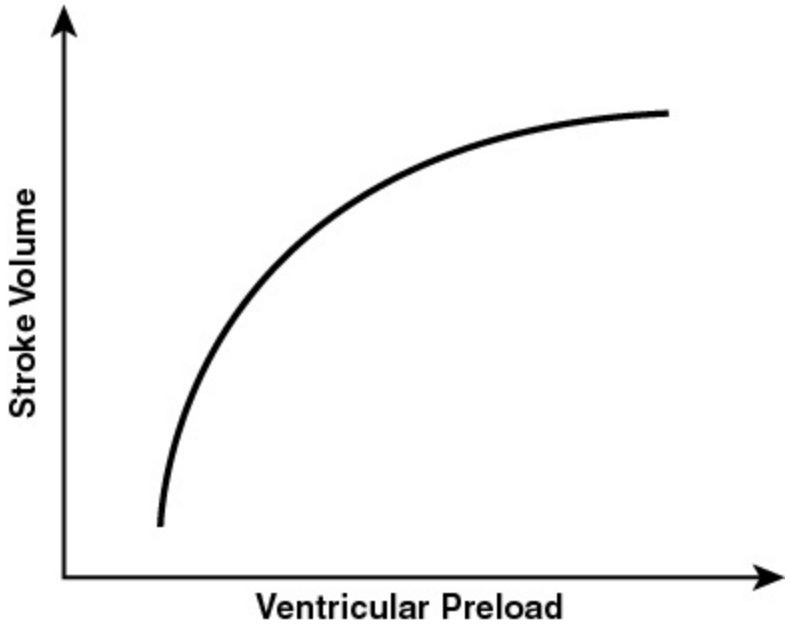
Contractility is the ability of myocardial fibers to shorten during systole. It is highly dependent on preload and afterload and is difficult to measure as an independent variable. Additional factors that can affect contractility in the critically ill patient are endogenous sympathetic activation, acidosis, ischemia, inflammatory mediators, and

vasoactive agents. An increase in contractility would result in a larger stroke volume. Echocardiographic measurement of the ejection fraction provides some information to the clinician on contractility.

2. Preload

Preload is a measure or estimate of the ventricular volume at the end of diastole (end-diastolic volume) and is determined by venous return and ventricular compliance. The distensibility or stretch (compliance) of the ventricle and the volume load (venous return) it can accept are the basis for the Frank-Starling curve. In general, a greater end-diastolic volume leads to increased stretch on the myocardium, resulting in a larger stroke volume (**Figure 6-3**). Because it is difficult to measure volume, preload is most often estimated from the ventricular end-diastolic pressure, which is transmitted and reflected in the atrial pressure. The atrial pressure is estimated by the measurement of pressure in a central vein or the pulmonary artery. Thus, the right ventricular preload is estimated by measurement of the central venous pressure (CVP) and the left ventricular preload by the measurement of pulmonary artery occlusion pressure. These pressures indirectly reflect the end-diastolic volume as well as the compliance of the ventricular wall. Using bedside ultrasonography, assessment of the change in the diameter of the inferior vena cava with respiration may aid in the assessment of right ventricular preload.

Figure 6-3. Relationship Between Ventricular Preload and Stroke Volume



When end-diastolic volume of the ventricle (preload) increases, stroke volume usually increases proportionately.

The relationship between the measured pressure and volume in the ventricular chambers depends upon the compliance or distensibility of the ventricle. During myocardial ischemia, sepsis, valvular dysfunction, and even tachycardia, the ventricles may become less compliant and may not fully relax during diastole. This diastolic dysfunction reduces the ventricular volume at end diastole but may be associated with a higher filling pressure; therefore, the clinician may misinterpret pressure measurements to indicate adequate volume loading. Changes in intrathoracic pressures (eg, tension pneumothorax, positive pressure ventilation) may also affect the filling pressures.

3. Afterload

Afterload is the myocardial wall tension required to overcome the resistance, or pressure load, that opposes ejection of blood from the ventricle during systole. The higher the afterload, the more tension the ventricle must develop, the more work is performed, and the less efficient the contraction may become. Afterload is usually estimated from the systemic mean arterial pressure (left ventricle) and mean pulmonary artery pressure (right ventricle) and by calculations of systemic and pulmonary vascular resistance.

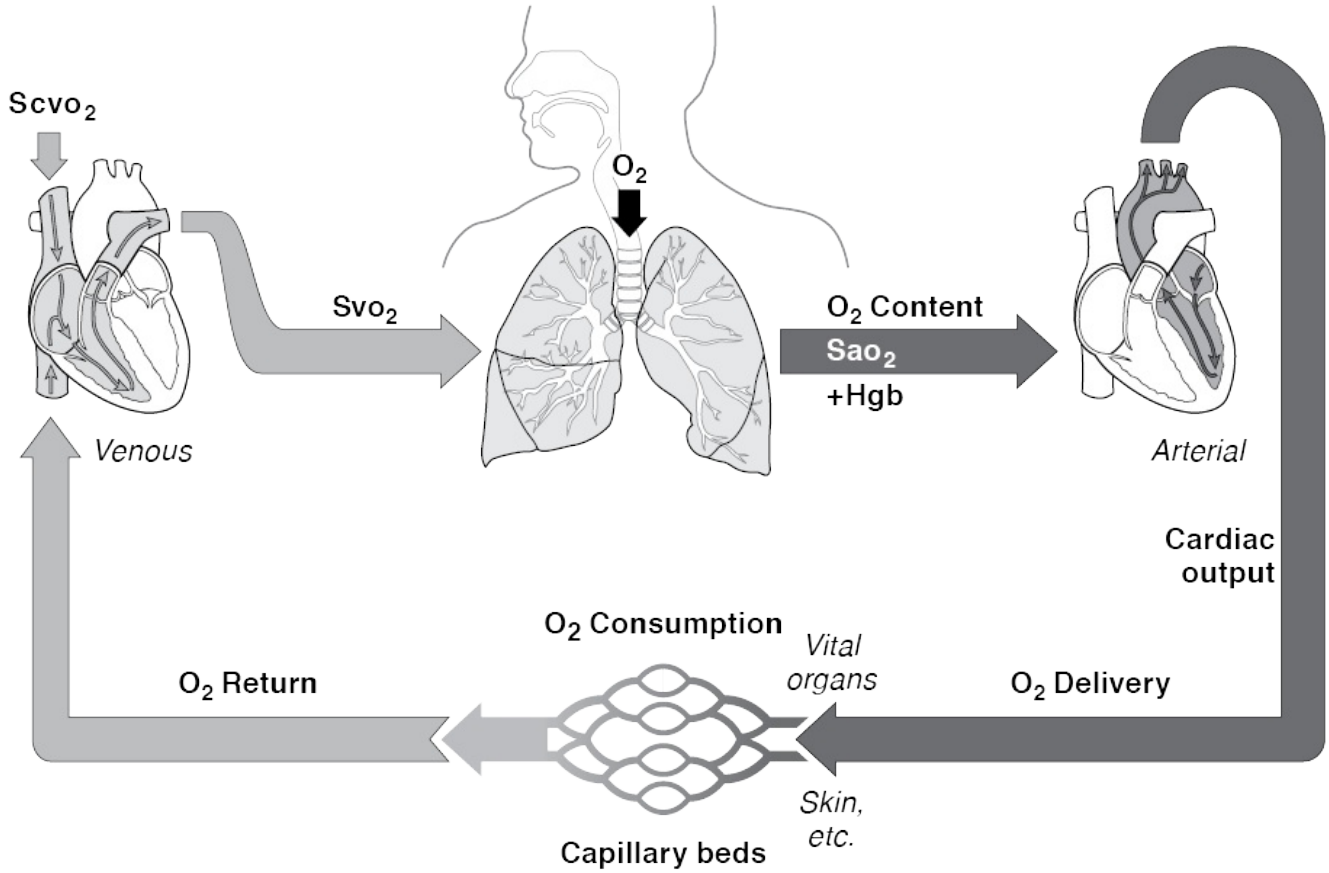
III. ASSESSMENT OF OXYGEN BALANCE

In addition to oxygen delivery, oxygen consumption by the tissues affects oxygen balance. However, less is known about the factors that determine oxygen utilization at the cellular and tissue levels, and no direct routine measures of oxygen consumption are available. Indirect calculated measurement of oxygen consumption requires invasive or complex techniques. These measures reflect global oxygen utilization and do not provide information on oxygen utilization by specific tissues or organs.

Measurements of global oxygen balance that may be useful in monitoring the seriously ill patient include central venous oxyhemoglobin saturation ($Scvo_2$) and lactate concentrations. $Scvo_2$ can be obtained continuously or intermittently from a catheter placed in the internal jugular or subclavian vein and correlates with the mixed venous oxyhemoglobin saturation (Svo_2) obtained from a pulmonary artery catheter in the pulmonary artery. The Svo_2 measures the oxyhemoglobin saturation of blood from the superior vena cava and the inferior vena cava that has been mixed in the right ventricle. These measures of venous oxyhemoglobin saturation represent the amount of oxygen still bound to hemoglobin after traversing the tissue capillaries and returning to the right heart; the decrease from the Sao_2 estimates the amount of oxygen utilized (**Figure 6-4**). In normal individuals, the Svo_2 is >65% and the $Scvo_2$ is 2% to 3% lower. However, in

patients with shock and/or hypoperfusion, the $Scvo_2$ may be 5% to 7% higher than the Svo_2 due to greater desaturation of venous blood from the gastrointestinal tract contributing to Svo_2. Low values of $Scvo_2$ suggest an imbalance in the oxygen supply and demand. This imbalance may be due to decreases in cardiac output, hemoglobin concentration, or Sao_2, or increases in tissue oxygen consumption. Patients may have more than one abnormality contributing to oxygen imbalance. A normal $Scvo_2$ may still be associated with tissue hypoxia in conditions such as severe sepsis and certain poisonings (eg, cyanide). Further evaluations of lactate concentration and organ function are needed to assess oxygen balance in the seriously ill patient when the $Scvo_2$ is normal.

Figure 6-4. Determinants of Oxygen Balance

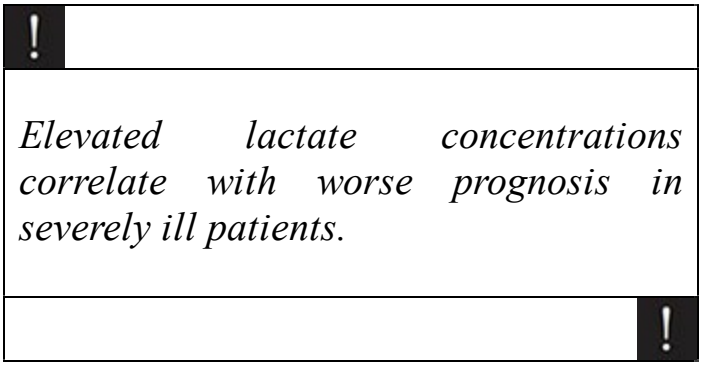


Abbreviations: Hgb, hemoglobin; Sao_2, arterial oxyhemoglobin saturation

Oxygen balance depends on the oxygen delivered to the tissues and the metabolic needs of those tissues. An estimate of the oxygen utilized by the tissues is provided by the central venous oxyhemoglobin value ($Scvo_2$) and mixed venous oxyhemoglobin saturation (Svo_2).

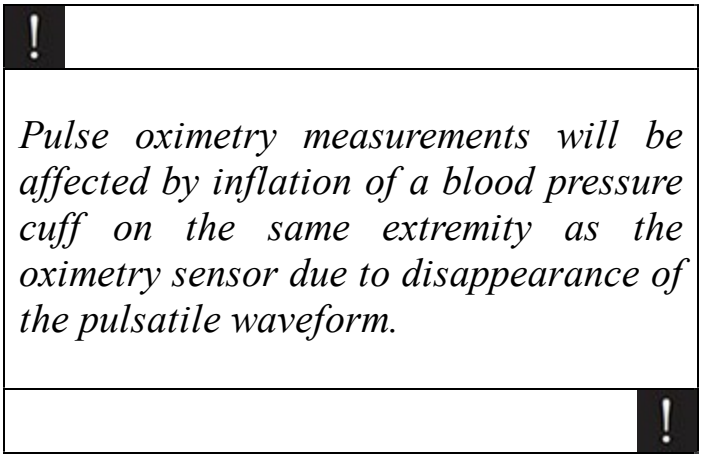
Lactate is another indicator of the overall oxygen balance. It is produced during anaerobic metabolism when cellular hypoxia occurs. The elevation of blood lactate in shock and hypoperfusion may be due to inadequate oxygen supply to tissue but also may

be affected by altered hepatic metabolism, use of vasoactive drugs, and other factors. Lactate concentrations do not have high sensitivity or specificity for inadequate tissue oxygenation, but elevated concentrations often are associated with tissue hypoperfusion. A decreasing lactate concentration may be a useful indicator of effective interventions.



IV. MONITORING DETERMINANTS OF OXYGEN BALANCE

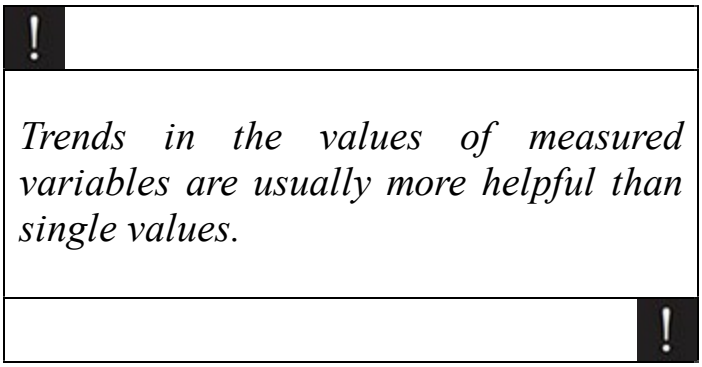
Precise monitoring of oxygen balance is not easily accomplished because techniques may not be available to assess some variables (contractility, tissue oxygen consumption) or special expertise and resources are required (stroke volume determination, echocardiography). However, monitoring of variables such as oxyhemoglobin saturation, blood pressure, Scv_{O_2}, lactate concentration, and fluid responsiveness combined with other clinical information, may provide guidance in evaluating the adequacy of oxygen balance in seriously ill patients.



A. Monitoring of Oxyhemoglobin Saturation

1. Principles

The pulse oximeter is a simple, noninvasive device that estimates arterial oxyhemoglobin saturation. The transmission of red and infrared light through the capillary bed creates several signals throughout the pulsatile cardiac cycle. These signals measure the absorption of the transmitted light by the tissue or venous and arterial blood. Calculations made from the processed signals provide estimates of the oxygen saturation of hemoglobin, expressed as a percentage. This is not the same as the Pa_{O_2} in the blood, although Pa_{O_2} is a primary determinant of the saturation of hemoglobin. Neither does it reflect adequacy of oxygen delivery or ventilation. The value measured by the device is commonly called the Sp_{O_2} to distinguish it as the oxyhemoglobin saturation measurement by a pulse oximeter rather than the Sa_{O_2}, which is determined directly from an arterial blood sample by co-oximetry. Pulse oximetry is useful in detecting hypoxemia and titrating the delivered oxygen concentration in patients receiving supplemental oxygen.



2. Clinical Issues

Studies have shown that to ensure a Pa_{O_2} of 60 mm Hg (8.0 kPa), an Sp_{O_2} of 92% should be maintained in patients with light skin, whereas 94% saturation may be needed in patients with dark skin. Oximetry sensors can be applied to the finger, toe, earlobe, bridge of nose, mouth, or any skin surface from which a reliable pulsatile signal can be obtained. Factors that can affect signal detection or fidelity are listed in **Table 6-2**. Pulse oximeters display a digital heart rate derived from the pulsatile signal detected by the sensor. This rate should equal the patient's heart rate as measured by another method, so these two rates should be compared as the first step in the analysis of an Sp_{O_2} measurement. Additional hemodynamic information may be obtained from the pulse oximeter waveform, which is related to the arterial blood pressure waveform and stroke volume. Variation in the pulse oximeter waveform (pulse pressure) with positive pressure ventilation may suggest hypovolemia and responsiveness to fluid administration (see next section).

Table 6-2 Factors That Affect Accuracy of Pulse Oximetry

Anatomic or Physiologic Factors
Dark skin
False nails
Nail polish
Hypothermia
Vasoconstriction
Hypotension
Poor regional perfusion
Hematocrit <15%
Hyperlipidemia
Carboxyhemoglobin
Tachycardias

External Factors
Lipid suspensions, propofol (falsely elevate the oxygen saturation)
Bright room lighting
Electrical interference
Poorly adherent probe
Excessive motion of the sensor

B. Blood Pressure Monitoring

Although blood pressure is not a direct determinant of oxygen balance, an appropriate driving pressure is necessary for oxygen delivery at the tissue level. Blood pressure is determined by the cardiac output and systemic vascular resistance according to the following relationship:

$$\text{Blood Pressure} = \text{Cardiac Output} \times \text{Systemic Vascular Resistance}$$

Blood pressure may be monitored invasively or noninvasively.

1. Automated Noninvasive Devices

a. Principles

Automated blood pressure devices are frequently used to obtain intermittent blood pressure measurements. These devices use one of several methods to measure systolic and diastolic pressures, but the most common method is oscillometry. Systolic and diastolic pressures and the mean arterial pressure are directly measured via appearance, disappearance, and amplitude of oscillating waves. The arm is the preferred measurement site in adults, but alternative sites include the calf, forearm, or thigh, the latter being the least comfortable site for patients. The cuff should not be placed on an extremity that is being used for intravenous infusion or in an area susceptible to circulatory compromise. The appropriate cuff size is necessary for

accurate measurements. A cuff that is too large will underestimate the true blood pressure, and a cuff that is too small yields artificially high measurements.

b. Clinical Issues

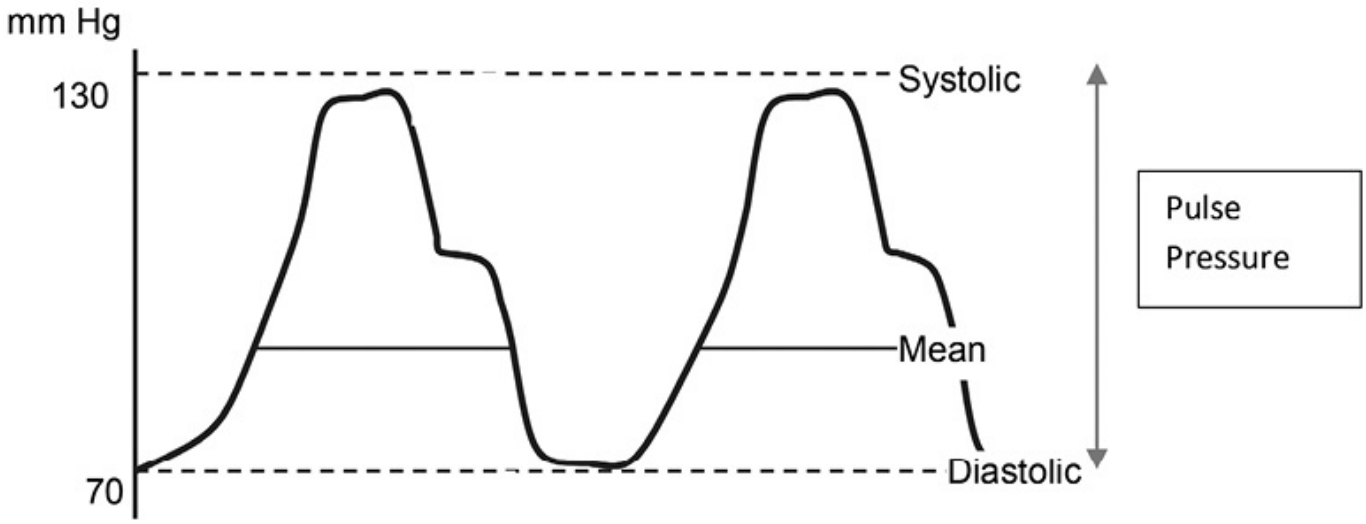
An adequate blood pressure measurement does not ensure adequate tissue perfusion. Automated blood pressure devices are less accurate in clinical situations commonly encountered with the critically ill patient, such as shock, vasoconstriction, mechanical ventilation, and arrhythmias. Shivering, muscle contraction, and movement of the extremity can lead to erroneous measurements. In such circumstances, repeat measurement is advised when these conditions are not present. Blood pressure monitoring via an arterial catheter is preferable to the use of an automated blood pressure device in hemodynamically unstable patients.

2. Arterial Cannulation

a. Principles

An indwelling arterial catheter allows for continuous measurement of blood pressure, pulse volume or pressure, and mean arterial pressure (**Figure 6-5**) by transduction of pressure via a specialized monitoring setup. Pulse pressure is the difference between the systolic and diastolic pressure measurements. It may also be used for arterial blood gas measurement. The primary indications for insertion of an arterial cannula are the need for frequent arterial samples and continuous assessment of arterial blood pressure. Use of an arterial catheter should be considered for arterial blood sampling if more than four samples are required in 24 hours. Arterial pressure monitoring may also be used with minimally invasive hemodynamic monitoring systems to evaluate cardiac output, stroke volume, or pulse pressure variation.

Figure 6-5. Appearance of Arterial Pressure Wave with Invasive Monitoring



When invasive monitoring is used, the calculation of the mean arterial pressure is based on the area under the curve.

The most common insertion sites for arterial catheters are (in order of preference for adults) the radial, femoral, axillary, and dorsalis pedis arteries. Brachial artery cannulation is usually avoided if possible because it is an end artery and hand ischemia is a potential complication. Shorter catheters are used for radial and dorsalis pedis artery insertion and longer catheters for insertion in femoral and axillary sites. Preferred sites have alternative collateral circulations. The choice of site is based on the presence of palpable pulses, general hemodynamic state, and other anatomic or physiologic factors unique to each patient.

!

The dorsalis pedis artery is less reliable for pressure monitoring in adults because of its size and distance from the heart.

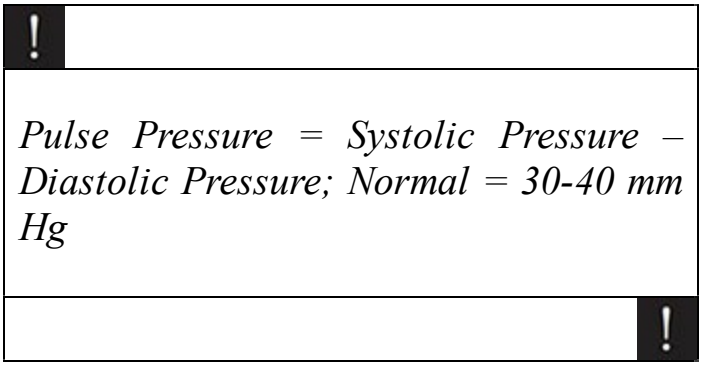
!

b. Clinical Issues

The arterial catheter is never used for infusion of any medications or fluids and must be monitored continuously. Concern about the accuracy of the intra-arterial pressure measurements should lead to a return-to-flow assessment with a manual blood pressure cuff. Measurements should be made after calibration of the catheter/transducer system at

or near the level of the heart.

Several technical and anatomic factors may affect the accuracy of the pressures obtained with the catheter system. Distortion of the arterial waveform signal may occur due to vascular alterations, the hydraulic coupling system of the transducer, the calibration of the transducer, or the maintenance of the pressurized system tubing. Inspection of the result may show an overdamped and domed waveform or the high-spiking "overshoot or ringing" pattern of the underdamped waveform. Both distortions have the greatest effect on the systolic and diastolic pressures, whereas the mean arterial pressure is less affected.



As with noninvasive monitoring, intra-arterial blood pressure monitoring may not be a sensitive indicator of hypoperfusion because of compensatory vasoconstriction. Additional clinical information regarding volume status can be obtained by visual inspection of the arterial blood pressure waveform in mechanically ventilated patients (**Figure 6-6**). Positive pressure during inspiration may decrease the stroke volume in patients with inadequate intravascular volume due to decreased venous return. The decrease in stroke volume leads to a decreased pressure that is visually represented as a systolic variation of blood pressure and a decrease in the pulse pressure. (See Section F.)

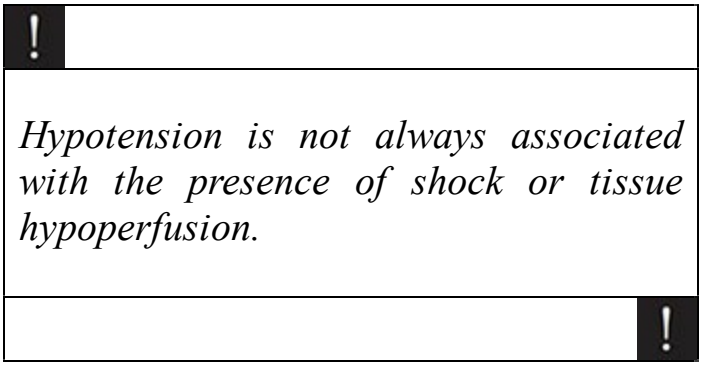
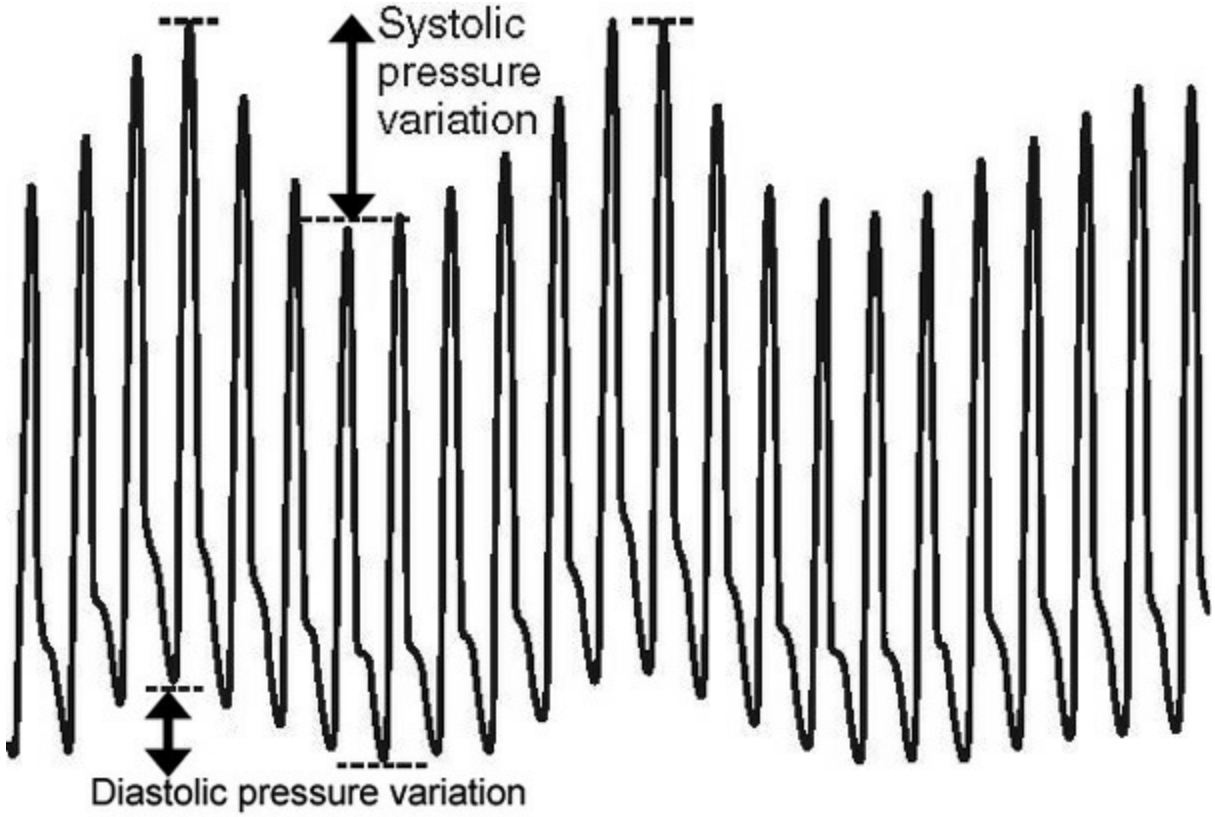


Figure 6-6. Variation of Blood Pressure in a Mechanically Ventilated Patient with Hypovolemia



With positive pressure applied during inspiration, the decrease in systolic pressure is greater than the decrease in diastolic pressure, resulting in a decrease in pulse pressure.

Possible complications associated with arterial catheter insertion are listed in **Table 6-3**. These can be minimized by careful insertion technique, appropriate catheter size for the artery, proper site care, and a continuous flush system. The arterial waveform must be continuously monitored and displayed, with alarm settings to prevent inadvertent blood loss through a catheter that is accidentally opened to the atmosphere. The extremity with the arterial catheter should be inspected frequently for evidence of ischemia or infection. Any sign of ischemia distal to the catheter or infection at the site of insertion requires immediate removal of the catheter. Arterial catheters should be removed as soon as possible to minimize the risk of infection.

Table 6-3	Possible Complications of Arterial Catheters

Hematoma formation
Blood loss
Arterial thrombosis
Proximal or distal embolization
Arterial pseudoaneurysm
Infection
Accidental administration of fluids or medications

C. Monitoring Right Ventricular Filling Pressures and $Scvo_2$

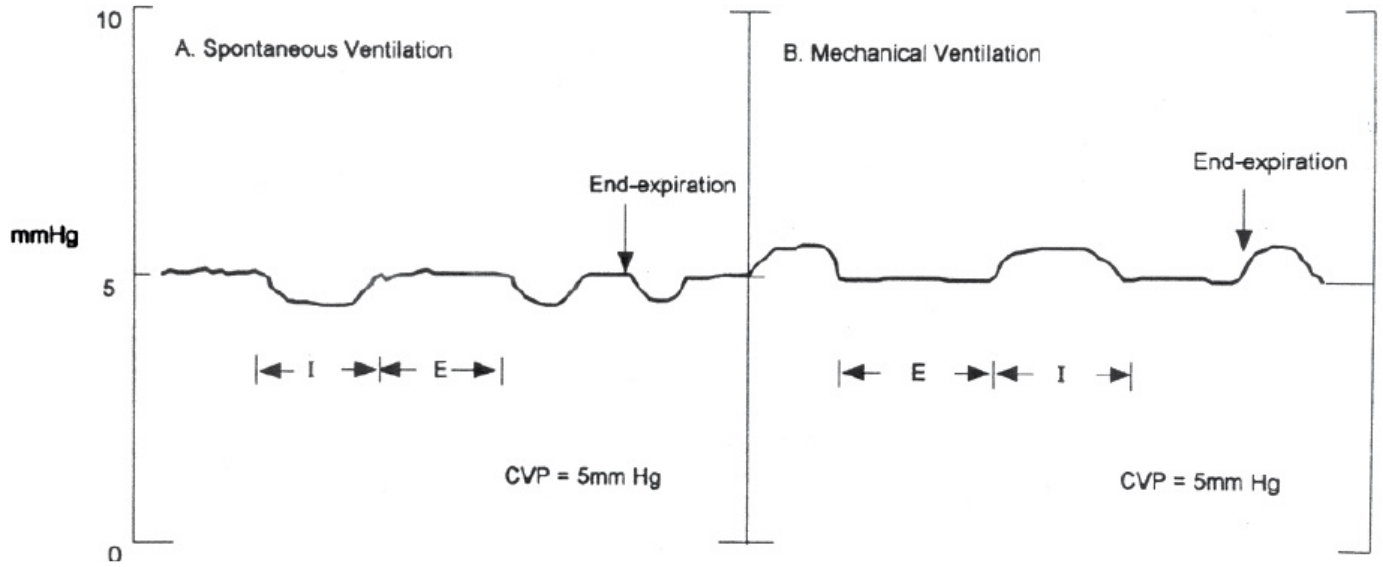
A central venous catheter in the internal jugular or subclavian vein allows measurement of CVP and $Scvo_2$. Placement of a central venous catheter may be indicated for other reasons as well (**Table 6-4**). Confirmation of catheter placement in the internal jugular or subclavian vein and the tip in the superior vena cava by chest radiography is recommended to ensure accurate measurements of CVP and $Scvo_2$ and to detect complications of the procedure.

Table 6-4

Common Indications for Central Venous Cannulation
Measurement of mean central venous pressure
Measurement of central venous oxygen saturation
Large-bore venous access
Difficult or long-term venous access
Administration of irritating drugs and/or parenteral nutrition
Hemodialysis
Placement of a temporary pacing wire
Placement of a pulmonary artery catheter

CVP, obtained from an appropriately positioned catheter, estimates the right ventricular filling pressure as a reflection of preload (end-diastolic volume). Normal values for CVP are 2 to 8 mm Hg, and measurements should be made at the end of expiration. Significant variation of the CVP waveform may occur during spontaneous breathing and mechanical ventilation, requiring visual assessment of the waveform to identify the end of expiration (**Figure 6-7**). In general, a low CVP indicates a low intravascular volume associated with a low preload. Normal or high CVP measurements must be evaluated cautiously, as they may not predict adequate or increased preload volume due to changes in intrathoracic pressures or ventricular compliance. Additional clinical assessment, such as fluid responsiveness, is required to estimate adequacy of preload with normal or elevated CVP measurements. Right ventricular preload estimates do not necessarily correlate with left ventricular preload.

Figure 6-7. Typical Cyclic Pattern for CVP Waveform



Typical cyclic pattern for continuous venous pressure (CVP) waveform that shows inspiration (I) and expiration (E). A, Respiratory variation during spontaneous ventilation: CVP decreases during spontaneous inspiration as intrapleural pressure decreases. B, Respiratory variation during positive pressure mechanical ventilation: CVP increases during delivery of the mechanical breath as positive pressure is transmitted from the airway to the intrapleural space and great vessels. The vertical arrows denote the point of end-expiration during spontaneous and mechanical ventilation

Scv_{O_2} can be monitored intermittently by withdrawal of blood for analysis or continuously with a catheter containing an oximeter to evaluate oxygen balance. Clinical protocols have used Scv_{O_2} measurements along with other parameters to determine adequacy of resuscitation. Normal Scv_{O_2} values are usually >65%.

D. Measuring Left Ventricular Filling Pressures

Left ventricular filling pressures are usually estimated from measurement of the pulmonary artery occlusion pressure. A pulmonary artery catheter is necessary to obtain this information but requires expertise in insertion, data collection, and data interpretation. The clinician should consult with a critical care practitioner if invasive monitoring with a pulmonary artery catheter is needed to obtain additional hemodynamic information. Static single measurements of left ventricular filling pressure can often be provided by echocardiography.

E. Measuring Cardiac Output

Cardiac output plays a key role in determining oxygen delivery to the tissues. Measurement methods – such as thermodilution with a pulmonary artery catheter, esophageal Doppler ultrasonography, and arterial waveform pulse pressure analysis –

require varying degrees of invasiveness as well as special expertise. In the absence of direct measurement of cardiac output, less-specific indicators of tissue oxygenation, such as lactate concentration and $Scvo_2$, may guide specific interventions until critical care expertise is available.

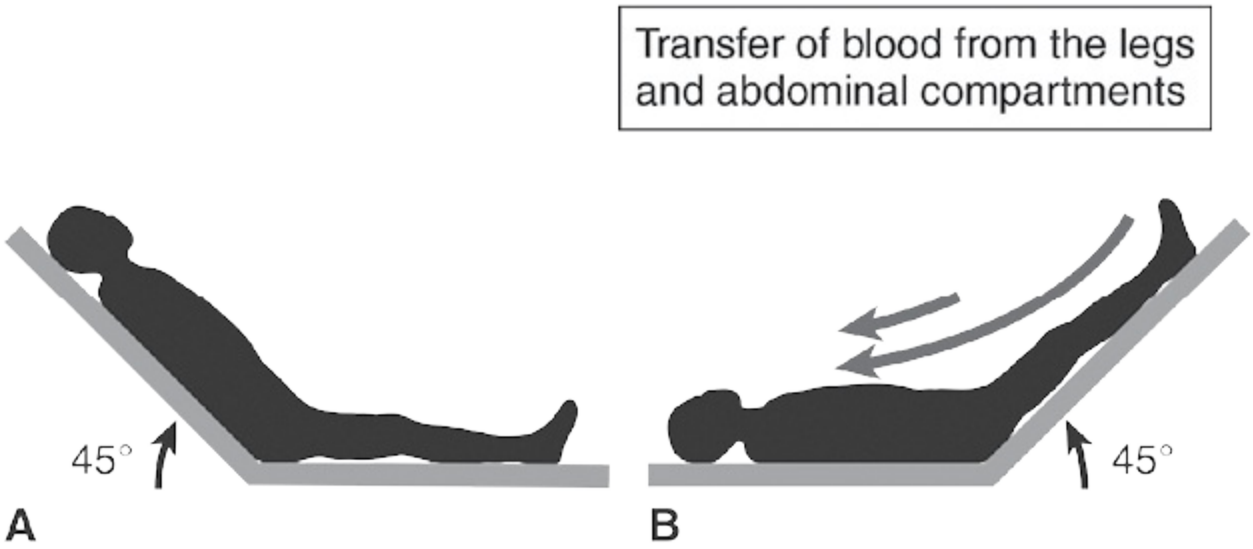
F. Monitoring Fluid Responsiveness

The practical question that clinicians often face in caring for critically ill patients is whether further fluid administration will improve cardiac output and oxygen delivery. This dilemma may not be adequately addressed by single measurements of heart rate, CVP, or blood pressure.

Significant variation (greater than 10% to 15%) in the cardiac output, stroke volume, systolic blood pressure, or pulse pressure in mechanically ventilated patients with evidence of impaired oxygen delivery may suggest the need for additional fluids to optimize cardiac output or the need to reduce intrathoracic pressures by decreasing tidal volume or positive end-expiratory pressure. With each positive pressure breath from the ventilator, venous return and right ventricular preload are decreased. If the right ventricle is dependent on preload, then positive pressure breaths will result in a decrease in the right ventricular stroke volume, leading to a decrease in left ventricular preload and left ventricular stroke volume (cardiac output) [**Figure 6-6**]. A variety of devices are available that can monitor variation in systolic blood pressure, pulse pressure, and/or stroke volume. All have limitations in accuracy that must be considered, such as adequate tidal volume, tachyarrhythmias, and adequate sedation.

Passive leg raising (PLR) is another technique that may be used at the bedside with less-invasive monitoring techniques to determine if additional fluid is beneficial. This maneuver is performed by placing the head of the bed flat from the semi-recumbent position and then raising both legs simultaneously to a 45° angle (**Figure 6-8**). This action results in a gravitational transfer of approximately 300 mL of blood from the lower limbs and splanchnic compartment toward the right heart. No fluid is infused and the clinical effects are completely reversible. If a significant increase in cardiac output or stroke volume is noted within 30 to 60 seconds of PLR, the patient is determined to be fluid responsive. PLR has been noted to be reliable in mechanically ventilated patients and patients with spontaneous respiratory effort who are not mechanically ventilated. If monitoring of cardiac output or stroke volume is not possible, a significant increase in blood pressure after the passive leg raise suggests that cardiac output has increased. No increase or an insignificant increase in blood pressure is less helpful in this circumstance. PLR should not be performed in patients with increased intracranial pressure and may not be reliable when intra-abdominal pressures are increased.

Figure 6-8. Effects of Passive Leg Raising



Fluid boluses may also be used to determine if a patient is fluid responsive. Boluses of isotonic crystalloid (usually 250-500 mL) are administered over a short period (5-10 minutes) and subsequent cardiac output or stroke volume measurements are noted. If a significant increase in cardiac output or stroke volume occurs following the bolus, the patient is fluid responsive. This technique must be used carefully as additional fluid may be detrimental to the patient's cardiac or respiratory status.

V. ACID-BASE DISORDERS

Acid-base disorders are common in the critically ill patient, and assessment of acid-base status may indicate specific diagnoses and/or therapeutic interventions. The presence of a metabolic acidosis should suggest hypoperfusion and prompt further assessment of the adequacy of the oxygen balance. An appropriate evaluation of acid-base status requires accurate interpretation of simultaneous measurements of electrolytes, albumin, and arterial blood gases, as well as knowledge of compensatory physiologic responses. **Appendix 5** includes acid-base case studies for practice in analyzing arterial blood gas and electrolyte information and in determining appropriate interventions.

A. Evaluation of Acid-Base Disorders

Analysis of acid-base disorders in seriously ill patients requires a systematic approach.

Although several methods can be utilized (base excess, strong ion difference), the approach below relies on traditional analysis using formulas based on hydrogen ion and bicarbonate (HCO_3) concentrations that can be applied at the bedside.

1. Determine the overall acid-base condition by measuring pH. Is acidemia or alkalemia present?
2. If an abnormality is present, determine if the primary process is metabolic (change in [HCO_3]) or respiratory (change in partial pressure of arterial carbon dioxide [$Paco_2$]).
3. If a respiratory disturbance is present, determine if it is an acute or a chronic process.
4. If a metabolic disturbance is present, determine if respiratory compensation is adequate.
5. Always calculate the anion gap (AG).

B. Metabolic Acidosis

Metabolic acidosis results from an increase in endogenous acid production that overwhelms renal excretion (eg, ketoacidosis, lactic acidosis), exogenous acid input (eg, toxin ingestion), excessive loss of bicarbonate (eg, diarrhea), or decreased renal excretion of endogenous acids (eg, renal failure). Compensation is achieved primarily by increasing minute ventilation to eliminate CO_2. The adequacy of respiratory compensation can be estimated by the following formulas:

$$\text{Appropriate } Paco_2 = 1.5 \times [HCO_3] + 8 \pm 2; \text{ or } \Delta Paco_2 = 1.2 \times \Delta[HCO_3]$$

The lower limit of respiratory compensation is usually a $Paco_2$ of approximately 10 mm Hg (1.3 kPa). This means the $Paco_2$ will not go lower than 10 mm Hg to compensate for a metabolic acidosis.

Metabolic acidosis is further characterized by a normal or increased anion gap. Normally, unmeasured anions exceed unmeasured cations, and the difference results in the AG, which is estimated by the following formula:

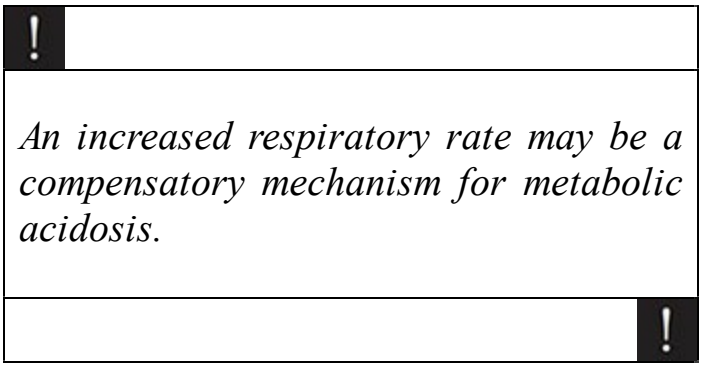
$$AG = [Na] - ([Cl] + [HCO_3])$$

The normal AG value is approximately 10 ± 4 mmol/L but the normal range varies by

laboratory. An increased AG indicates an increase in unmeasured anions and/or a decrease in unmeasured cations. An increased AG has limitations as the sole indicator of a metabolic acidosis. In patients with severe hypoalbuminemia, an AG acidosis can exist even when a normal AG is measured. In such patients, the expected AG may be as low as 4 to 5 mmol/L. For every albumin decrease of 1 g/dL, a decrease of 2.5 to 3 mmol in AG will occur. The corrected AG can be calculated using the following formula:

$$AG_{corrected} = AG_{observed} + 2.5 \times [\text{normal albumin-measured albumin (in g/dL)}]$$

Another exception can occur when an elevated AG does not reflect an underlying acidosis. In patients with significant alkalemia (usually pH >7.5), albumin is more negatively charged, which increases unmeasured anions.



An increased respiratory rate may be a compensatory mechanism for metabolic acidosis.

In seriously ill patients, the most common causes of metabolic acidosis with an increased AG are lactic acidosis, renal failure, and diabetic ketoacidosis. Metabolic acidosis with a normal AG, often called *hyperchloremic acidosis*, may result from gastrointestinal or renal loss of HCO_3 or volume resuscitation with normal saline.

C. Metabolic Alkalosis

Metabolic alkaloses are usually characterized as chloride-depleted (hypovolemic, which is the most common type) and chloride-expanded (hypervolemic). Hypokalemia is common to both types of metabolic alkalosis. Measurement of urine chloride is helpful in distinguishing the two categories, with urine chloride <20 mmol/L in chloride-depleted metabolic alkaloses and urine chloride >20 mmol/L in chloride-expanded metabolic alkaloses. Diuretic therapy is a common cause of hypovolemic metabolic alkalosis in hospitalized patients. Normal compensation for metabolic alkalosis is hypoventilation, which is limited by hypoxemia as $Paco_2$ increases in patients breathing spontaneously. $Paco_2$ may rise 6 to 7 mm Hg (0.8-0.9 kPa) for every increase of 10 mmol/L in [HCO_3]. Treatment includes volume replacement for chloride-

depleted states and assessment of the renal-adrenal axis for chloride-expanded conditions. Potassium deficiencies should be corrected. Severe alkalemia is associated with high mortality and requires aggressive treatment.

D. Respiratory Acidosis

Respiratory acidosis is most commonly due to ineffective alveolar ventilation. If the respiratory acidosis is acute, the pH decreases by 0.08 units for each increase of 10 mm Hg (1.3 kPa) in $Paco_2$. A very small increase in plasma [HCO_3] can be seen acutely because of titration of intracellular non-bicarbonate buffers. For each acute increase of 10 mm Hg (1.3 kPa) in $Paco_2$, the [HCO_3] increases by 1 mmol/L to a maximum of 30 to 32 mmol/L. In chronic respiratory acidosis, the pH decreases 0.03 units and the [HCO_3] increases 3.5 mmol/L for each increase of 10 mm Hg (1.3 kPa) in $Paco_2$. The limit of normal renal compensation in chronic respiratory acidosis is an [HCO_3] of approximately 45 mmol/L. Higher values suggest an associated metabolic alkalosis. Treatment of respiratory acidosis involves the rapid identification of the etiology and implementation of corrective action. In some circumstances, intubation and mechanical ventilation may be necessary to support alveolar ventilation.

E. Respiratory Alkalosis

Respiratory alkalosis results from primary hyperventilation due to a variety of etiologies. Acute pulmonary processes or an acidosis should be considered in the seriously ill patient. Similar to changes noted in respiratory acidosis, pH increases 0.08 for every decrease of 10 mm Hg (1.3 kPa) in $Paco_2$ in acute respiratory alkalosis, and pH increases 0.03 for each decrease of 10 mm Hg (1.3 kPa) in $Paco_2$ in chronic respiratory alkalosis. The [HCO_3] decreases 2 mmol/L in acute respiratory alkalosis and 5 mmol/L in chronic respiratory alkalosis for each decrease of 10 mm Hg (1.3 kPa) in $Paco_2$. Chronic respiratory alkalosis is unique among acid-base disorders in that pH may return to normal if the condition is prolonged. Therapy is directed to the underlying cause.

F. Complex Acid-Base Disorders

Simple acid-base disorders result from a single process such as metabolic alkalosis. In many critically ill patients, multiple acid-base disturbances exist concurrently and result in complex acid-base disorders. For example, sepsis often presents with respiratory

alkalosis and metabolic acidosis. A systematic approach to acid-base analysis is needed to identify the ongoing disturbances and determine appropriate diagnoses and interventions. Formulas that are helpful in evaluating acid-base status are listed in **Table 6-5**.

Table 6-5 Acid-Base Formulas

Acid-Base Disorder	Equation
Respiratory Acidosis	
Acute	Decrease in pH = $0.08 \times \frac{(Pa_{CO_2} - 40)}{10}$
	Increase in $[HCO_3 = \frac{\Delta Pa_{CO_2} \pm 3}{10}$
Chronic	Decrease in pH = $0.03 \times \frac{(Pa_{CO_2} - 40)}{10}$
	Increase in $[HCO_3 = 3.5 \times \frac{\Delta Pa_{CO_2}}{10}$
Respiratory Alkalosis	
Acute	Increase in pH = $0.08 \times \frac{(40 - Pa_{CO_2})}{10}$
	Decrease in $[HCO_3 = 2 \times \frac{\Delta Pa_{CO_2}}{10}$
Chronic	Increase in pH = $0.03 \times \frac{(40 - Pa_{CO_2})}{10}$
	Decrease in $[HCO_3 = 5 - 7 \times \frac{\Delta Pa_{CO_2}}{10}$
Metabolic Acidosis	Anion Gap = [Na] – ([Cl] + $[HCO_3$)
	Expected Pa_{CO_2} = 1.5 × $[HCO_3$ + 8 ± 2 or expected ΔP_{CO_2} = 1.2 × $\Delta[HCO_3$
Metabolic Alkalosis	Increase in Pa_{CO_2} = 0.6 – 0.7 × $\Delta[HCO_3$

Key Points

Monitoring Oxygen Balance and Acid-Base Status

- Oxygen delivery is dependent on cardiac output (blood flow) and the oxygen content of arterial blood.
- Hemoglobin is the major contributor of oxygen for tissue demands.
- Normal ventricular filling pressure measurements may not indicate adequate preload volume.
- Measurements of global oxygen balance that may be useful to monitor in the seriously ill patient include central venous oxyhemoglobin saturation ($Scvo_2$) and lactate concentrations.
- Low $Scvo_2$ values suggest an oxygen imbalance that may be due to decreases in cardiac output, hemoglobin concentrations, or arterial oxyhemoglobin saturation, or increases in tissue oxygen consumption.
- The pulse oximeter estimates arterial oxyhemoglobin saturation but does not reflect adequacy of oxygen delivery.
- Blood pressure monitoring via an arterial catheter is preferable to the use of an automated blood pressure device in unstable patients.
- Determination of systolic blood pressure, pulse pressure, or stroke volume variation and fluid responsiveness using special monitoring devices may be helpful in optimizing cardiac output and oxygen delivery.
- Assessment of acid-base status may suggest specific diagnoses and/or therapeutic interventions.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Gauthier PM, Szerlip HM. Metabolic acidosis in the intensive care unit. *Crit Care Clin*. 2002;18:289-308.
2. Kellum JA. Disorders of acid-base balance. *Crit Care Med*. 2007;35:2630-2636.
3. Marx G, Reinhart K. Venous oximetry. *Curr Opin Crit Care*. 2006;12:263-268.
4. Whittier WL, Rutecki GW. Primer on clinical acid-base problem solving. *Dis*

Mon. 2004;50:122-162.

5. Mohammed I, Phillips C. Techniques for determining cardiac output in the intensive care unit. *Crit Care Clin*. 2010;26:355-364.
6. Monnet X, Teboul J-L. Minimally invasive monitoring. *Crit Care Clin*. 2015;31:25-42.
7. Jubran A. Pulse oximetry. *Crit Care*. 2015;19:272.
8. Monnet X, Teboul J-L. Assessment of volume responsiveness during mechanical ventilation: Recent advances. *Crit Care*. 2013;17:217.
9. Monnet X, Teboul J-L. Passive leg raising. *Intensive Care Med*. 2008;34:659-663.
10. Hartog C, Bloos F. Venous oxygen saturation. *Best Prac Res Clin Anaesthesiol*. 2014;28:4194-28.
11. Magder S. Central venous pressure: A useful but not so simple measurement. *Crit Care Med*. 2006;34:2224-2227.
12. Kraut JA, Madias NE. Lactic acidosis. *N Engl J Med*. 2014;371:2309-2319.

Suggested Website

1. Ortega R, Hansen CJ, Elterman K, et al. Videos in clinical medicine: Pulse oximetry. *N Engl J Med*. 2011;364:e33. http://www.nejm.org/multimedia/medical-videos.

DIAGNOSIS AND MANAGEMENT OF SHOCK

Objectives

- Identify the four main categories of shock.
- Discuss the goals of resuscitation in shock.
- Summarize the general principles of shock management.
- Describe the physiologic effects of vasoactive and inotropic agents.
- Discuss the diagnosis and management of oliguria and acute kidney injury.

Case Study

A 54-year-old man was admitted to the floor with an edematous and erythematous right lower extremity. Purulent drainage is seen. Vital signs include a temperature 39.0°C (102.2°F), heart rate of 140 beats/min, respiratory rate 26 breaths/min, and blood pressure of 110/58 mm Hg.

– What information is needed to determine if this patient has shock?

– What initial interventions are needed to stabilize the patient?

I. INTRODUCTION

Shock is a syndrome of impaired tissue oxygenation and perfusion caused by many different etiologies. Prompt recognition of shock and early, effective intervention are needed to prevent irreversible injury, organ dysfunction, and death. Inadequate tissue oxygenation and perfusion may result from one or more of the following mechanisms:

- An absolute or relative decrease in systemic oxygen delivery (inadequate cardiac

output, low blood oxygen content)

- Ineffective tissue perfusion (maldistribution of blood flow to tissues or inadequate perfusion pressure)
- Impaired utilization of delivered oxygen (cellular or mitochondrial dysfunction)

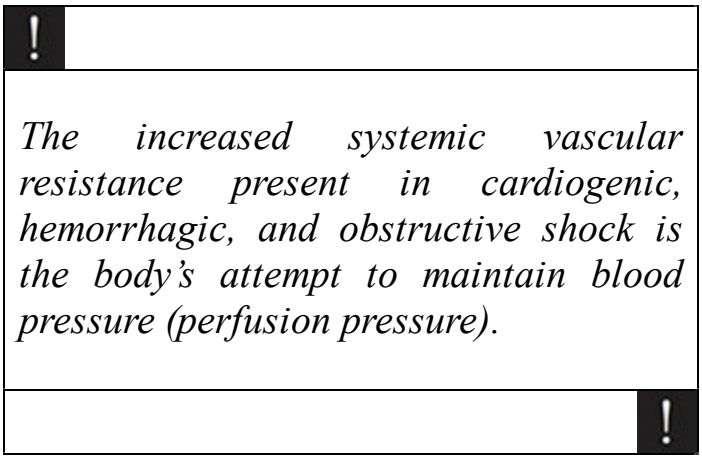
Shock results when the oxygen balance is disturbed and demand exceeds supply. Shock is not defined by the presence of hypotension, although hypotension is frequently associated with shock. In some patients with shock, the blood pressure initially may be normal even though it has significantly dropped from baseline, or it may be preserved due to compensatory sympathetic responses. Management of shock should be directed toward correcting tissue oxygenation and hypoperfusion as the primary end points.

II. CLINICAL ALTERATIONS IN SHOCK

The presentation of patients with shock may be subtle (eg, mild confusion, sinus tachycardia) or easily identifiable (profound hypotension, anuria). Shock may be the initial manifestation of an underlying condition, or it may develop as the condition progresses. A strong index of suspicion and vigilant clinical assessment and monitoring are needed to identify the early signs and initiate appropriate treatment. The clinical manifestations of shock result from inadequate tissue oxygenation and perfusion, compensatory responses, and the specific etiology of shock. Hypoperfusion may cause hypotension, altered mental status, oliguria/anuria, and other organ dysfunction. In addition, hypoperfusion is associated with some degree of inflammatory response that may contribute to organ injury. Direct and indirect effects of hypoperfusion may be reflected in laboratory findings of abnormal oxygenation, blood urea nitrogen, creatinine, bilirubin, hepatic transaminases, and coagulation parameters. An anion gap metabolic acidosis is a common finding of hypoperfusion and is often associated with an elevated lactate concentration. Although neither sensitive nor specific for the diagnosis of shock, the lactate concentration is an indicator of global oxygen balance and hypoperfusion and is a useful monitoring tool for assessment of therapeutic interventions (See **Chapter 6**).

Compensatory mechanisms in shock involve complex neuroendocrine responses that attempt to increase tissue perfusion and oxygenation. In many forms of shock, sympathetic vasoconstriction redirects blood flow from low-oxygen-requiring organs (eg, skin) toward oxygen-dependent organs (eg, brain and heart). Compensatory vasoconstriction can maintain blood pressure early in shock and lead to an increase in the diastolic pressure and a narrowing of the pulse pressure. Intense vasoconstriction

correlates with cold, clammy extremities and contributes to organ hypoperfusion. Hypothermia also may be a manifestation of severe vasoconstriction. Patients with distributive shock (see below) often have vasodilation and warm extremities, but other signs of hypoperfusion are usually present. Tachycardia, mediated by the sympathetic response, reflects an attempt to increase cardiac output in shock. Tachypnea may be a compensatory response to metabolic acidosis, a response to lung injury, or a reaction to direct stimulation of the respiratory center.



The increased systemic vascular resistance present in cardiogenic, hemorrhagic, and obstructive shock is the body's attempt to maintain blood pressure (perfusion pressure).

Additional changes in shock alter oxygenation at the tissue level. As discussed in **Chapter 6**, hemoglobin releases more oxygen as it traverses the capillaries in order to meet tissue demands. A rightward shift of the oxyhemoglobin saturation curve due to acidosis or increased temperature facilitates release of hemoglobin-bound oxygen. The greater extraction of oxygen is reflected in lower mixed venous oxyhemoglobin saturation (Svo_2) or central venous oxyhemoglobin saturation ($Scvo_2$) measurements in many forms of shock (**Chapter 6**). However, a normal value for either of these measurements does not imply that tissue oxygenation is adequate, because some forms of shock (eg, septic shock) may lead to impaired tissue or cellular utilization of oxygen or result in maldistribution of blood flow.

III. CLASSIFICATION OF SHOCK

There are four main categories of shock based on cardiovascular characteristics: hypovolemic, distributive, cardiogenic, and obstructive (**Table 7-1**). A careful history and a physical examination often provide information that is helpful in determining the likely cause of shock. However, many patients will have components of more than one type (mixed shock). Septic shock is a form of distributive shock, but it may have a hypovolemic component before fluid resuscitation. Likewise, myocardial dysfunction may be present in septic shock and hypovolemic shock.

Table 7-1	Classification of Shock
Hypovolemic	**Cardiogenic**
Hemorrhagic	Myopathic (ie, ischemic)
Nonhemorrhagic	Mechanical (ie, valvular)
	Arrhythmic
Distributive	**Obstructive**
Septic	Massive pulmonary embolism
Adrenal crisis	Tension pneumothorax
Neurogenic (upper spinal cord injury)	Cardiac tamponade
Anaphylactic	Constrictive pericarditis

Knowledge of the expected hemodynamic profiles associated with different types of shock is helpful in determining appropriate therapy, even when specific measurements are not available. **Table 7-2** presents the usual hemodynamic profiles for more common forms of shock, but variations occur depending on the patient's specific etiology, cardiac function, and resuscitation status.

Table 7-2	Hemodynamic Profiles of Shock					
Type of Shock	**Heart Rate**	**Cardiac Output**	**Ventricular Filling Pressures**	**Systemic Vascular Resistance**	**Pulse Pressure**	**S_{vo_2} or Scv_{o_2}**
Cardiogenic	↑	↓	↑	↑	↓	↓
Hypovolemic	↑	↓	↓	↑	↓	↓
Distributive	↑	↑ **or N[a]**	↓	↓	↑	↑ **or N[a]**
Obstructive	↑	↓	↑ **or N[b]**	↑	↓	↓

Abbreviations: Svo_2, mixed venous oxyhemoglobin saturation; $Scvo_2$, central venous oxyhemoglobin saturation; N, normal

[a]May be decreased before or early in resuscitation.

[b]Left ventricular filling pressures may be normal or low in massive pulmonary embolism.

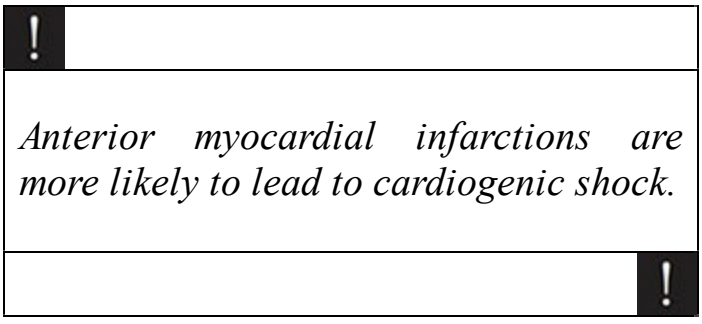
A. Hypovolemic Shock

Hypovolemic shock occurs when intravascular volume is depleted relative to the vascular capacity as a result of hemorrhage, gastrointestinal or urinary fluid losses,

dehydration, or third-space fluid losses. Third-space fluid losses resulting from interstitial fluid redistribution may be prominent in burn injury, trauma, pancreatitis, and any severe form of shock. The hemodynamic findings in hypovolemic shock are decreased cardiac output, decreased right and left ventricular filling pressures (preload), and an increased afterload (systemic vascular resistance [SVR]) due to compensatory vasoconstriction. The Svo_2 or $Scvo_2$ is decreased as a result of decreased cardiac output with unchanged or increased tissue oxygen demands and potentially decreased hemoglobin concentration (hemorrhage). In addition to the usual clinical findings, patients with hypovolemic shock have flat, nondistended jugular veins.

B. Distributive Shock

Distributive shock is characterized by loss of peripheral vascular tone (vasodilation). However, these patients often have components of hypovolemic shock and cardiogenic shock. The most common form of distributive shock is septic shock, with neurogenic shock and anaphylactic shock being much less common. The hemodynamic profile usually includes a normal or increased cardiac output with a low SVR and low to normal ventricular filling pressures. A decreased cardiac output may result if intravascular volume is not optimized. $Scvo_2$ or Svo_2 may be normal or increased due to shunting of blood in the microvasculature or the inability of tissue to utilize oxygen (as in sepsis). In contrast to other forms of shock, the vasodilation of fluid-resuscitated distributive shock results in warm extremities, decreased diastolic pressure, and increased pulse pressure. Neurogenic shock due to cervical or upper thoracic spinal cord dysfunction or injury may be associated with bradycardia rather than tachycardia. Fever may be present in septic shock and adrenal crisis.



C. Cardiogenic Shock

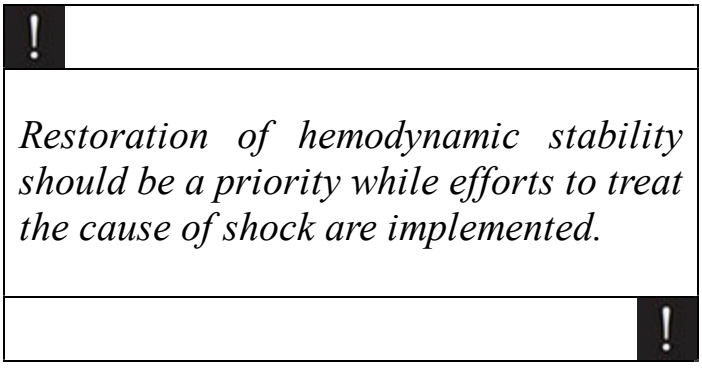
In cardiogenic shock, forward blood flow is inadequate because of cardiac pump failure due to loss of functional myocardium (ischemia, cardiomyopathy), a mechanical or structural defect (valvular failure, septal defect), or arrhythmias. Most commonly,

cardiogenic shock results from acute myocardial infarction or a subsequent complication. Cardiogenic shock is the most severe form of heart failure and is distinguished from less severe chronic heart failure by the presence of hypoperfusion, hypotension, and the need for different therapeutic interventions (**Chapter 10**). The typical hemodynamic characteristics are decreased cardiac output, elevated ventricular filling pressures, and increased afterload (SVR). When cardiac output is low, the Svo_2 or $Scvo_2$ declines due to decreased oxygen delivery and increased extraction of oxygen from the hemoglobin at tissue level. Clinical manifestations associated with cardiogenic shock may include distended jugular veins, pulmonary edema, and S_3 gallop.

D. Obstructive Shock

The common features in obstructive shock are obstruction of flow due to impaired cardiac filling and excessive afterload. Cardiac tamponade impairs diastolic filling of the right ventricle, while tension pneumothorax limits right ventricular filling by obstruction of venous return. Massive pulmonary emboli increase right ventricular afterload. The hemodynamic profile is characterized by decreased cardiac output, increased afterload, and variable left ventricular filling pressures, depending on the etiology. In cardiac tamponade, the pressures of the right heart chambers, the pulmonary artery, and the left heart chambers equilibrate in diastole. A drop of >10 mm Hg in systolic blood pressure during inspiration (pulsus paradoxus) is an important clinical finding in patients with suspected cardiac tamponade. Distended jugular veins may be seen, depending on the time course of development and intravascular volume status.

IV. GENERAL PRINCIPLES OF SHOCK MANAGEMENT



The overall goal of shock management is to improve oxygen delivery or utilization in order to prevent cellular and organ injury. Effective therapy requires treatment of the underlying etiology, restoration of adequate perfusion, monitoring, and comprehensive

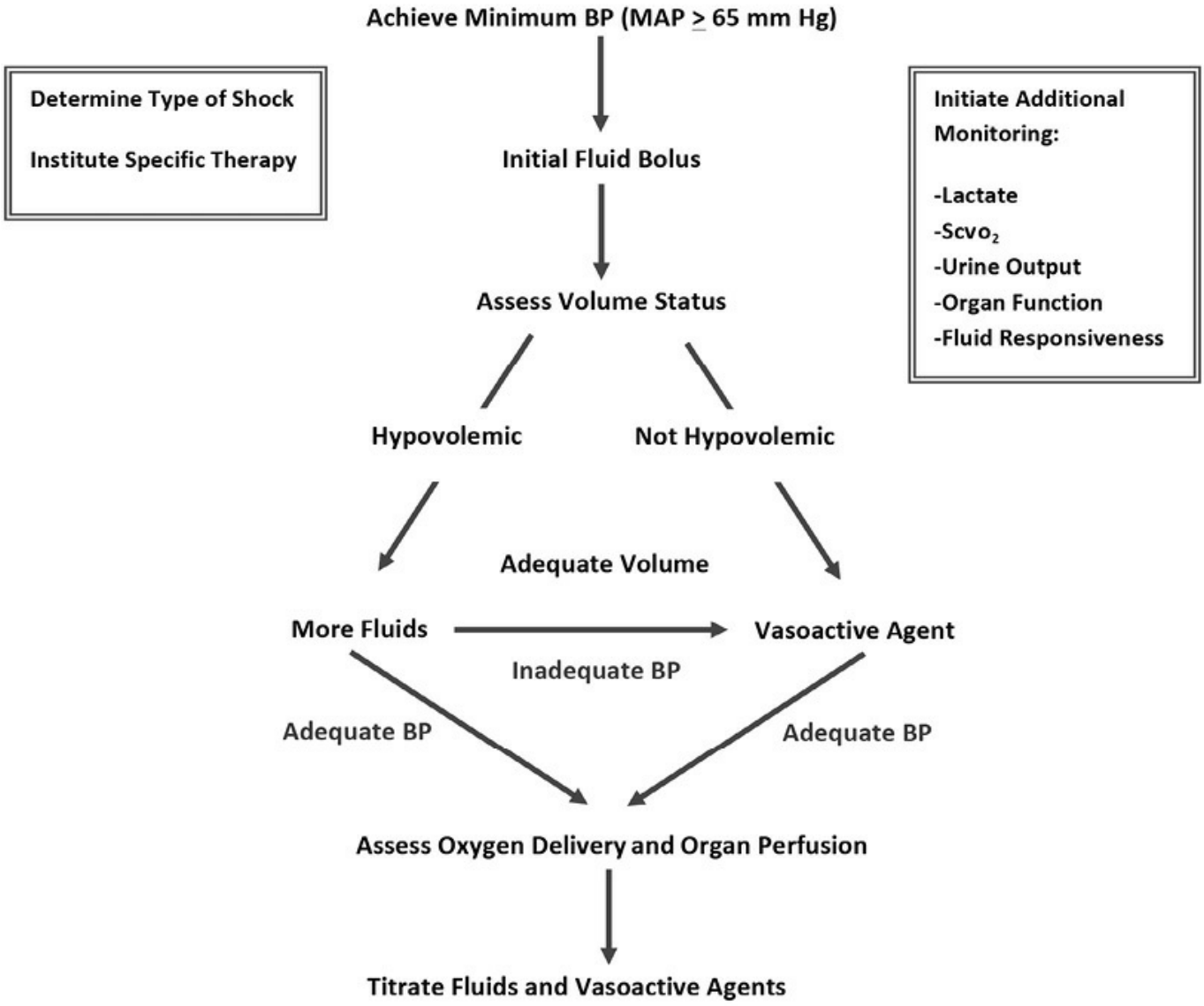
supportive care. Interventions to restore perfusion center on achieving an adequate blood pressure, increasing cardiac output, and/or optimizing the oxygen content of blood. Oxygen demand should also be decreased when possible. These goals are usually accomplished with a combination of interventions, as summarized in **Table 7-3** and **Figure 7-1**.

Table 7-3 Interventions for Managing Shock

Component	Intervention
Blood pressure	Fluids, vasopressor or vasodilator agents[a]
Cardiac Output	
Preload	Fluids, vasodilator agents[a]
Contractility	Inotropic agents
Afterload	Vasopressor or vasodilator agents[a]
Oxygen Content	
Hemoglobin	Blood transfusion
Hemoglobin saturation	Supplemental oxygen, mechanical ventilation
Oxygen demand	Mechanical ventilation, sedation, analgesia, antipyretics

[a]Vasodilator agents are used only when blood pressure is adequate.

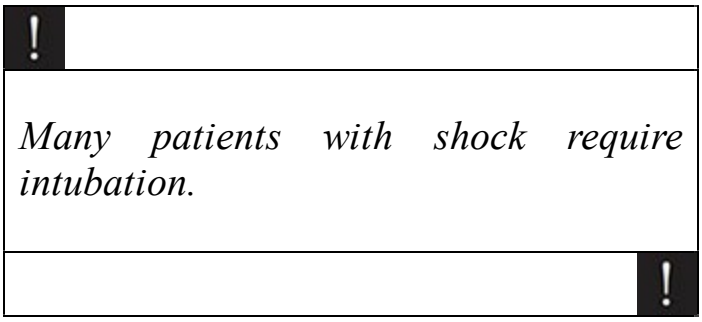
Figure 7-1. Approach to the Patient With Shock



Key aspects of initial shock management include a blood pressure goal, with titration of fluids and vasoactive drugs to assure adequate intravascular volume and mean arterial pressure >65 mm Hg. After these initial objectives are achieved, oxygen delivery and organ perfusion may be assessed by using such monitors as lactate levels, central venous oxygen saturation ($ScVO_2$), urine output and evidence of end organ performance. Fluid responsiveness may be determined by invasive hemodynamic monitoring systems or simple tests such as straight leg raising.

The first goal in treating hypotensive shock is to achieve a minimum blood pressure (driving pressure). This is needed to maintain blood flow to the heart and other organs while optimizing other components of oxygen delivery. A mean arterial pressure (MAP) ≥65 mm Hg is usually recommended as an initial goal. A higher MAP may be needed in patients with myocardial ischemia or chronic hypertension, but an increase in blood pressure is beneficial only if it translates into improved perfusion. Otherwise, higher blood pressures may increase myocardial oxygen demands. Following initial resuscitation, the MAP goal should be individualized based on further assessment of the

adequacy of systemic and organ perfusion. A blood pressure goal is usually achieved with fluids and/or vasoactive agents (see below).

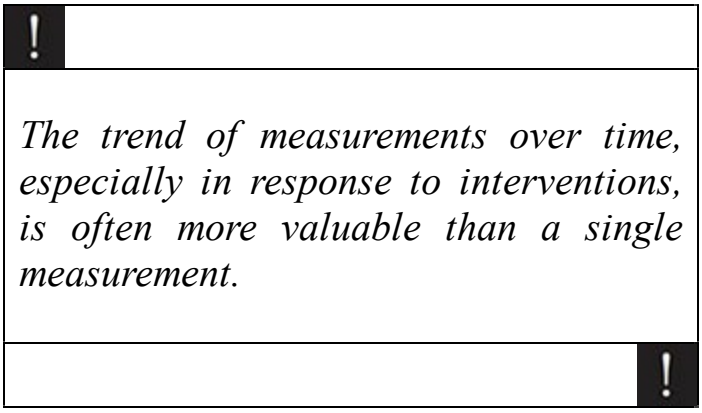


The next goal in the management of shock is to optimize oxygen delivery. As outlined in **Chapter 6**, this can be enhanced by increasing cardiac output, hemoglobin concentration, or oxyhemoglobin saturation. In the absence of specific measurement of cardiac output or stroke volume, an assessment of adequacy depends on the etiology of shock and the presence of hypoperfusion abnormalities (see below). Fluids and/or vasoactive agents are often needed to optimize cardiac output. The determinants of the oxygen content of blood (hemoglobin and oxyhemoglobin saturation) can be easily measured and optimized when indicated. Increasing the hemoglobin concentration by transfusion may be one of the most efficient ways of improving oxygen delivery in some patients. For example, increasing the hemoglobin concentration from 7 g/dL to 9 g/dL increases oxygen delivery by almost 30%, even if cardiac output remains constant. The oxyhemoglobin saturation can be increased by raising the partial pressure of arterial oxygen with oxygen supplementation and mechanical ventilation. However, once the partial pressure of arterial oxygen has been increased to a range of 60 to 70 mm Hg (8-9.3 kPa), little additional benefit is gained by increasing it further. An oxyhemoglobin saturation ≥95% is recommended in patients with shock.

A. Monitoring

Patients with shock require monitoring to determine appropriate interventions and assess response to interventions (**Chapter 6**). Continuous electrocardiographic monitoring is needed to assess changes in heart rate and rhythm. Blood pressure is best monitored with an arterial catheter due to the inaccuracies of noninvasive devices in patients with shock. Pulse oximetry should be monitored routinely to ensure adequate oxyhemoglobin saturation. A low central venous pressure in the appropriate clinical situation may suggest inadequate intravascular volume. Measurement of $Scvo_2$ via a central venous catheter may be useful as an indicator of oxygen balance, but a normal $Scvo_2$ value does not rule out hypoperfusion. A urinary catheter should be inserted to monitor urine output as an indicator of renal perfusion, with a suggested goal of 0.5 to 1

mL/kg/h. Lactate concentrations and acid-base status should be assessed initially and at appropriate intervals. Normal or decreasing lactate concentrations or improving acidosis suggest improved oxygen balance. Other laboratory data should be considered to assess progression or improvement of organ dysfunction.



B. Fluid Therapy

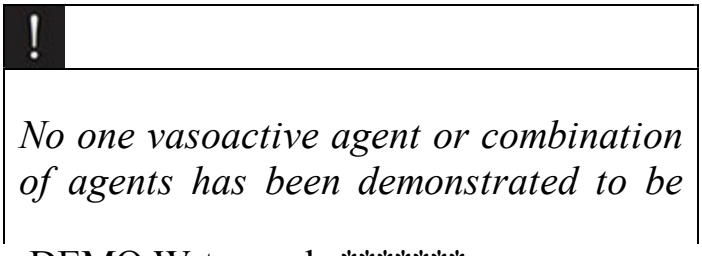
The initial therapy for most forms of shock is expansion of intravascular volume. Physical examination may provide valuable information about the intravascular volume status. Diffuse or dependent crackles, as well as distended neck veins, suggest high ventricular filling pressures, unless acute respiratory distress syndrome or diffuse pneumonia is present (or other causes of increased pulmonary pressure). Clear lung fields and flat neck veins suggest inadequate preload in the hypotensive patient. While orthostatic changes in blood pressure and heart rate may be helpful in determining the degree of volume depletion, the tachycardic hypotensive patient should not be subjected to these positional changes. The nature and degree of fluid deficits should be determined to identify the type and appropriate quantity of fluid replacement. Monitoring of fluid responsiveness, as described in **Chapter 6**, may be helpful in determining the appropriate volume of fluids.

Intravascular volume deficiency in the patient who is not anemic may be replenished with either crystalloid or colloid solutions. Crystalloids are less expensive than colloids and typically accomplish the same goals, although a higher total volume is needed due to their higher volume of distribution. Isotonic rather than hypotonic crystalloid solutions, such as lactated Ringer solution or normal saline, should be used for volume resuscitation. Dextrose 5% in water offers little expansion of intravascular volume since it is quickly distributed throughout body fluid compartments and should not be used to treat hypovolemic shock. For the same reasons, 0.45% saline is not appropriate for volume expansion. Colloid solutions include hetastarch, albumin, and gelatins. Use of albumin is limited by cost in some areas. Hetastarch use has been

associated with an increased risk of renal injury in septic shock. Crystalloid in titrated boluses of 500 to 1000 mL (10-20 mL/kg) or colloid in titrated boluses of 250 to 500 mL may be given initially to most adult patients and repeated as necessary while appropriate parameters are closely monitored. Smaller bolus amounts are indicated for patients with suspected or known cardiogenic shock.

In addition to crystalloid or colloid solutions, packed red blood cells are indicated to increase oxygen-carrying capacity in the patient with significant bleeding or anemia. In many critically ill patients, a hemoglobin concentration of 7 to 9 g/dL may be adequate after stabilization. Fresh frozen plasma should be used only for correction of a coagulopathy and not for volume replacement. Priorities in the administration of fluids are resuscitation and then replacement of ongoing losses. As the clinical course continues, the solution that most closely approximates the patient's losses should be used, with serum electrolytes guiding therapy.

The first goal in fluid resuscitation is correction of hypovolemia. Often, this correction manifests clinically as resolution of tachycardia, hypotension, or oliguria. However, these end points may remain altered despite euvolemia in states such as septic (distributive), neurogenic, or obstructive shock. Vasoactive drug support is indicated in patients who continue to have a low blood pressure or impaired cardiac output after euvolemia has been established, or who no longer have a beneficial response to fluid challenge or passive leg raising. The potential deleterious effects of overly aggressive fluid resuscitation include deterioration of oxygenation due to pulmonary edema, ileus or bowel edema, and compartment syndromes. Therefore, frequent auscultation of the chest for the presence of crackles, and monitoring of partial pressure of arterial oxygen or oxyhemoglobin saturation by pulse oximetry, should be performed during fluid resuscitation. Intra-abdominal pressure monitoring should be considered in patients requiring massive fluid resuscitation (**Chapter 13**). In the absence of advanced hemodynamic monitoring, volume therapy should be administered carefully in patients with persistent hypotension and/or hypoperfusion until no further change is noted in the blood pressure following a fluid bolus. This suggests that additional fluid no longer improves the patient's cardiac output and administration of more fluid can lead to the deleterious effects noted. Further correction of hypotension or other perfusion abnormalities may require pharmacologic support with vasoactive drugs. This approach to volume therapy presents minimal risk in patients with adequate oxygenation.



No one vasoactive agent or combination of agents has been demonstrated to be

superior in managing shock.

C. Vasoactive Agents

Vasoactive agents for the acute management of shock include medications with vasopressor, inotropic, and vasodilator effects. A vasopressor is a medication that results in arteriolar constriction, a rise in systemic vascular resistance, and a rise in arteriolar blood pressure. An inotrope is a medication that augments cardiac contractility. Many agents have more than one hemodynamic effect, and results may vary among individual patients and with dosage. The goals of resuscitation are usually more important than the specific agent chosen. **Table 7-4** summarizes each vasoactive drug and its mechanism of action. An intensivist should be consulted when the decision to use vasoactive medications is made.

Table 7.4 Vasoactive Agents

	DA-R (↑UOP)	β_1[a] (↑ HR)	β_2[b] (↓BP)	α_1[c] (↑ BP)
Dopamine 1-20 µg/kg/min	1-5 µg/kg/min	6-10 µg/kg/min		>10 µg/kg/min
Phenylephrine 1-300 µg/min				+++
Norepinephrine 0.01-0.5 µg/kg/min		+		++++
Epinephrine 0.01-0.5 µg/kg/min		++++	+++	++++
Dobutamine (1-20 µg/kg/min)		+++	++	
Milrinone[d] (0.125-0.5 µg/kg/min)		+++	+++	

Abbreviations: DA-R, dopamine receptor; UOP, urine output; HR, heart rate; BP, blood pressure
Potency scale is from 1+ to 4+
[a]β_1 = adrenergic receptor that increases cardiac contractility and/or heart rate
[b]β_2 = adrenergic receptor that mediates bronchodilation and arteriole dilation
[c]α_1 = adrenergic receptor that mediates arteriole constriction and increase in peripheral vascular resistance
[d]Milrinone is a phosphodiesterase inhibitor with indirect β_1 and β_2 effects.

1. Norepinephrine

Norepinephrine is the initial vasoactive drug recommended in the treatment of septic shock. It is a potent α-adrenergic vasoconstrictor with greater potency than either dopamine or phenylephrine, and it also has β_1-mediated inotropic and chronotropic effects. In adults, the infusion rate of norepinephrine starts at 0.05 μg/kg/min and is titrated to desired effects. As with other vasoconstrictors, cardiac output may decrease as afterload and blood pressure are increased. Norepinephrine usually increases renal blood flow in patients with adequate volume resuscitation. An increase in heart rate is uncommon with use of norepinephrine.

2. Dopamine

Dopamine is a less frequently used vasoactive agent with dose-dependent inotropic and vasopressor effects. It is no longer a drug of choice in the treatment of septic shock. Although dose response varies greatly among patients, some generalizations about dose and anticipated effect may be helpful. At low rates of infusion (1-5 μg/kg/min), dopamine has modest inotropic and chronotropic effects. In this dose range, it acts on the dopaminergic receptors in the kidney and may increase urine output; however, its use for renal effects is not recommended because it does not prevent renal dysfunction or improve outcomes. At intermediate rates of infusion (6-10 μg/kg/min), dopamine has primarily inotropic effects. At higher infusion rates (≥10 μg/kg/min), it has significant α-agonist effects that produce dose-related vasoconstriction. At infusion rates ≥20 μg/kg/min, dopamine usually offers no advantage over norepinephrine, which may have greater vasopressor effect. Potential adverse effects include arrhythmias (particularly atrial fibrillation) and tachycardia.

3. Epinephrine

Epinephrine has both α-adrenergic and β-adrenergic effects, potent inotropic and chronotropic effects, and at higher doses, vasopressor effects. Doses start at 0.05 μg/kg/min and can be titrated as desired. The epinephrine-induced increase in myocardial oxygen consumption may limit the use of this agent in adults, especially in the presence of coronary artery disease. Epinephrine can also increase aerobic lactate production rather than hypoperfusion-induced anaerobic lactate production.

4. Phenylephrine

Phenylephrine is a pure α-adrenergic vasoconstrictor. In adults, the infusion rate starts at 25 μg/min and can be titrated to the desired blood pressure. Because its mechanism of action involves solely arterial constriction, it is most useful in states with arterial dilation without concomitant cardiac depression, such as neurogenic shock or hypotension caused by an epidural anesthetic.

5. Vasopressin

Vasopressin is a potent vasopressor that acts through V_1 receptors to produce vasoconstriction. As blood pressure is increased, cardiac output may decrease, similar to the effect of norepinephrine. The recommended dose in adults is 0.01 to 0.04 units/min. Higher doses may lead to ischemic events. Vasopressin may be considered for use in hypotensive shock refractory to other agents and fluid resuscitation, but it has not been found to improve mortality. Further studies are needed to define the role of vasopressin in the management of shock.

6. Dobutamine

Dobutamine is a non-selective β-adrenergic agonist with inotropic effects. It is used in doses of 5 to 20 μg/kg/min and is usually associated with an increase in cardiac output, which is mediated mostly by an increase in stroke volume. Arterial blood pressure may remain unchanged, decrease, or increase slightly. Dobutamine must be introduced with care in the hypotensive patient; in the face of inadequate intravascular volume replacement, blood pressure can drop precipitously, and tachycardia may be problematic. This agent has variable chronotropic effects.

7. Milrinone

Milrinone is a phosphodiesterase inhibitor that inhibits the breakdown of cyclic adenosine monophosphate, the second messenger for catecholamines. Therefore, milrinone is a sympathomimetic agent with mostly β-adrenergic-like effects. It will increase cardiac output mostly by increasing stroke volume and will decrease afterload by causing arteriolar dilation. It should be used with caution in hypovolemic patients because it can cause significant hypotension.

D. End Points of Resuscitation

No one end point can be used to assess resolution of shock and return to normal homeostasis. Furthermore, fluid and pharmacologic therapy should be titrated based on the trend for the particular end point rather than its absolute value.

Blood pressure, pulse, and urine output are the most commonly used end points in resuscitation of shock. All parameters can be easily measured but lack sensitivity and specificity for either detection of impending shock or its resolution. As such, they may be normal if the patient is in a state of compensated shock, and they may remain abnormal despite appropriate therapy (eg, low blood pressure and urine output despite reaching a euvolemic state). Similarly, urine output may not be a reliable end point in

patients with preexisting or new renal dysfunction.

In addition to the clinical evaluation of vital signs and urine output, monitoring techniques that assess cardiac output or stroke volume may be helpful in determining when fluid resuscitation is optimized as an end point (**Chapter 6**, Monitoring Fluid Responsiveness). More invasive and complex monitoring techniques and measurements, such as pulmonary artery catheters, require special expertise to obtain, interpret, and apply results. $Scvo_2$ and lactate concentrations as measurements of global oxygen balance may also be useful in monitoring the patient in shock and assessing the impact of interventions. Neither measurement assesses the need for fluid versus pharmacologic support of the circulation. Normalization of organ function as assessed by laboratory values (such as renal or liver chemistries) is another end point to assess, but these measurements are not usually helpful in the first 24 hours.

V. MANAGEMENT OF SPECIFIC TYPES OF SHOCK

A. Hypovolemic Shock

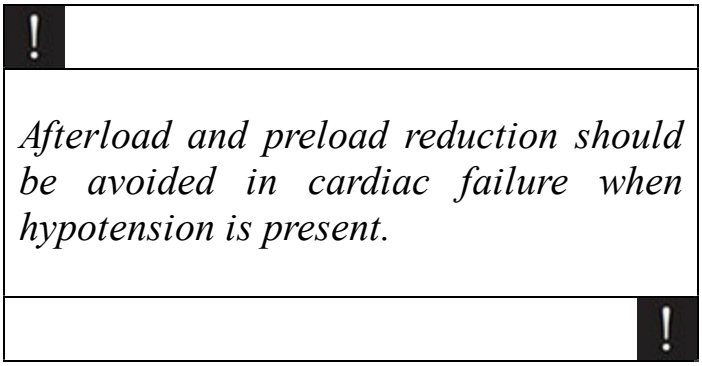
The treatment goals in hypovolemic shock are restoration of intravascular volume and prevention of further volume loss. Therapy for hypovolemic shock should be targeted to reestablish normal blood pressure, pulse, and organ perfusion. For initial resuscitation, either colloid or crystalloid fluids are effective if given in sufficient volume. Subsequently, the fluid that is used should replace the fluid that has been lost. For example, blood products may be needed to replace blood loss (**Chapter 9**), and crystalloid should be used for vomiting and dehydration. For hypotension, the crystalloid of choice is normal saline or lactated Ringer solution because of the osmolality needed to restore intravascular volume. In large volume resuscitation, however, normal saline infusion may produce hyperchloremic metabolic acidosis. Vasoactive medications should be considered only as a temporizing measure while fluid resuscitation is ongoing or when hypotension persists despite adequate volume resuscitation. Central venous pressure monitoring may help to guide fluid resuscitation in patients without significant heart or lung disease.

B. Distributive Shock

The initial approach to the patient with septic shock is restoration and maintenance of adequate intravascular volume. Obtaining cultures and prompt administration of

appropriate antibiotics are essential, as are other interventions to control the infection (removal of catheter, surgery, drainage, debridement). Lactate concentration should be measured and repeated if abnormal as one component of assessing the resuscitation efforts. Hypotension and lactate ≥4 mmol/L identify more severely ill patients with greater risk of dying.

Volume expansion can be initiated with isotonic crystalloid solutions. Vasodilation and diffuse capillary leakage are common in septic shock, and fluid requirements may be large. Colloid solutions can be considered along with crystalloids initially for patients with severe hypotension or those who require substantial amounts of crystalloids. If the patient with septic shock remains hypotensive despite adequate fluid resuscitation, norepinephrine is recommended as the initial vasoactive drug. Epinephrine can be considered for patients who fail to respond adequately to norepinephrine, but no agent has been shown to improve survival. Dobutamine may be considered in those with adequate blood pressure who have hypoperfusion and evidence of low cardiac output with adequate preload. Reversible myocardial dysfunction with ventricular dilation and decrease in ejection fraction frequently occurs in shock, especially septic shock. An initial MAP <65 mm Hg may require initiation of vasoactive pharmacologic therapy until fluid resuscitation is optimized. Corticosteroids (hydrocortisone 200 mg in 24 hours administered in divided doses or continuous infusion) may be considered in patients with septic shock when adequate fluids and vasoactive medications fail to restore hemodynamic stability. Anaphylactic shock is treated with volume resuscitation and subcutaneous epinephrine. In circumstances of very low blood pressure and poor peripheral perfusion, titrated intravenous epinephrine is indicated. Acute adrenal insufficiency is treated with volume therapy, intravenous corticosteroids, and vasoactive medications, if needed (**Chapter 12**). **Chapter 8** contains information about the management of neurogenic shock.



C. Cardiogenic Shock

The primary goal in treating cardiogenic shock is to improve myocardial function.

Arrhythmias should be treated promptly. Reperfusion by percutaneous intervention is the treatment of choice in cardiogenic shock due to myocardial ischemia (**Chapter 10**). Diastolic dysfunction during myocardial ischemia may decrease ventricular compliance and elevate the left ventricular filling pressures, falsely indicating adequate preload. Therefore, a cautious trial of fluid administration may be warranted (250-mL bolus amounts). When blood pressure is decreased in cardiogenic shock, initial therapy with a single agent that has inotropic and vasopressor effects (eg, norepinephrine or dopamine) is indicated. Severely hypotensive patients (systolic arterial pressure <70 mm Hg) should be treated with norepinephrine to rapidly raise the systolic arterial pressure. The addition of an intravenous inotrope, such as milrinone or dobutamine (or dopexamine, which is available in some countries), may be considered to augment myocardial contractility after blood pressure stabilizes, with the goal of decreasing vasopressor therapy. If moderate hypotension is not responsive to initial therapy, consultation should be sought for potential interventions such as intra-aortic balloon counterpulsation or left/right ventricular assist devices.

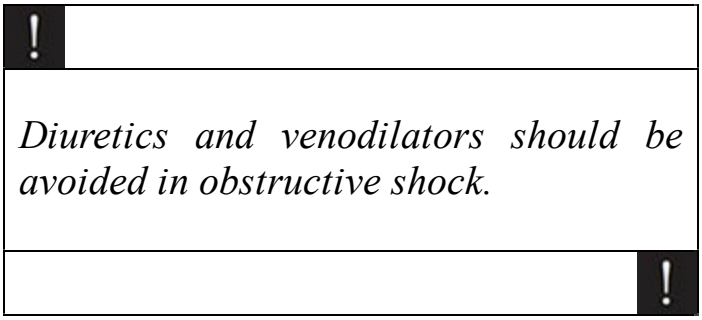
The elevated afterload (SVR) may also impair cardiac output if it is a primary hemodynamic alteration, as occurs in chronic congestive heart failure. Often in acute cardiogenic shock, the SVR is secondarily elevated to maintain vascular perfusion pressure. Treatment aimed primarily at reducing afterload with a vasodilator should be initiated very cautiously and only in patients with hypoperfusion accompanied by adequate blood pressure.

When cardiac failure is characterized by low cardiac output, normal or elevated blood pressure, and hypoxemia due to high pulmonary capillary pressure, reduction of preload and afterload is helpful in improving hypoxemia. High pulmonary capillary pressure can be diagnosed clinically. Preload reduction is accomplished with loop diuretics (furosemide or bumetanide) and venodilators (nitroglycerin and morphine), whereas afterload reduction is accomplished with arterial vasodilators (angiotensin-converting enzyme inhibitors or, occasionally, nitroprusside). If the blood pressure can be increased to normal levels with inotropes, then the cautious addition of afterload and preload reduction is feasible in the presence of low cardiac output or high pulmonary capillary pressure.

D. Obstructive Shock

In the patient with obstructive shock, relief of obstruction is the treatment of choice. Additionally, maintenance of intravascular volume is vitally important. Fluid resuscitation may improve the patient's cardiac output and hypotension temporarily. Inotropes or vasopressors have a minimal role in the management of obstructive shock,

and these agents provide only temporary improvement, if any. Massive pulmonary embolus is a common cause of obstructive shock. Treatment is centered on fluid resuscitation to maintain cardiac output and prompt anticoagulation to prevent clot propagation (**Chapter 13**). Thrombolytic therapy or thrombectomy is needed in rare cases of refractory cardiac collapse. If cardiac tamponade is present, pericardiocentesis may be lifesaving. Tension pneumothorax must be treated promptly by needle decompression and subsequent tube thoracostomy.



VI. OLIGURIA AND ACUTE KIDNEY INJURY

The kidneys are frequently affected by impaired oxygen balance and perfusion in all forms of shock. Oliguria, defined as urine output <0.5 mL/kg/h in adults, is an important manifestation of hypoperfusion or decreased glomerular filtration rate. Oliguria may be an earlier indicator of renal dysfunction than changes in laboratory parameters. Persistence of oliguria for at least 6 hours is one criterion for acute kidney injury (AKI). Hypoperfusion may also result in an increase of serum creatinine and blood urea nitrogen, which are the most common measures of renal function. Acute changes in serum creatinine and urine output are used to define AKI and classify severity across a broad range of renal dysfunction. A key point is that small alterations in creatinine (even a serum creatinine increase of 0.3 mg/dL [26.5 µmol/L] within 48 hours) or urine output predict an increased risk of renal failure and require further evaluation. Along with other parameters mentioned previously, resolution of oliguria may be considered a goal of resuscitation in shock. Oliguria also may be due to inherent renal injury or postrenal obstruction, in which case urine output cannot be used as a goal of adequate resuscitation. Causes of oliguria and AKI are categorized as prerenal, renal, and postrenal, as outlined in **Table 7-5**.

Table 7-5	Differential Diagnosis of Oliguria and Acute Kidney Injury
	Prerenal • Decreased cardiac output (eg, volume depletion, cardiac failure,

tamponade)
- Redistribution of blood flow (distributive shock) with peripheral vasodilation and/or shunting

Renal
- Glomerular disease (glomerulonephritis)
- Vascular disease (eg, vasculitis)
- Interstitial disease (eg, antibiotics)
- Renal tubular disease
- Ischemia
- Nephrotoxic drugs

Postrenal (Obstructive)
- Bilateral ureteral obstruction
- Urethral stricture
- Bladder outlet obstruction
- Urinary catheter obstruction

[a]Fractional excretion of sodium = ([urine sodium ÷ serum sodium] ÷ [urine creatinine ÷ serum creatinine]) × 100.

Additional laboratory tests may help differentiate prerenal causes of oliguria and AKI from other etiologies. Some laboratory tests of renal function are shown in **Table 7-6**.

Table 7-6 Laboratory Tests to Distinguish Prerenal Conditions from Acute Tubular Necrosis

Laboratory Tests	Prerenal	Acute Tubular Necrosis
Blood urea nitrogen/creatinine ratio	>20	10-20
Urine specific gravity	>1.020	>1.010
Urine osmolality (mOsm/L)	>500	<350
Urinary sodium (mmol/L)	>20	>40
Fractional excretion of sodium (%)[a]	<1	>2

Management of oliguria or AKI due to shock or other etiologies in the critically ill patient should follow an organized approach. The patient should be evaluated promptly to determine the cause of renal dysfunction. Reversible causes should always be rapidly identified and corrected. Insertion of a urinary catheter and a renal ultrasound scan will exclude urinary obstruction in most patients. The urinary catheter is also a useful device to monitor urine output and should be utilized in patients with shock. More frequent measurements of blood urea nitrogen, serum creatinine, and urine output are needed. Volume status should be assessed using clinical examination and the monitoring techniques outlined in **Chapter 6**. Intravascular volume should be optimized with crystalloid and/or colloid solutions to improve renal perfusion. Vasoactive drugs along

with fluids may be needed in patients with shock in order to achieve an adequate blood pressure. Loop diuretics may be considered (if blood pressure is adequate) in the setting of volume overload. Although the conversion to a nonoliguric state does not change outcome, fluid management is usually easier, especially in patients with severe hypoxemic respiratory failure. No evidence supports the use of low-dose dopamine in oliguric patients. Once oliguric or anuric AKI is confirmed and persistent, fluids should be restricted to the replacement of ongoing losses (including insensible losses). In disease states associated with ongoing loss of intravascular volume, fluid administration is necessary to maintain adequate left ventricular preload. These losses may be substantial, as in pancreatitis, severe sepsis, and large open wounds.

Because there is no specific treatment for most cases of AKI, expectant and supportive care is maintained. Drug dosages need adjustment not only for the severity of AKI but also for the type of renal replacement therapy that may be utilized. Nephrotoxic drugs (such as intravenous contrast) should be avoided if possible. Monitoring of drug concentrations should be utilized to guide therapy when possible. Problems with extracellular fluid overload, hyperkalemia, and hypermagnesemia should be anticipated and avoided if possible. Hyperkalemia usually can be managed medically until dialysis is available (**Chapter 12**). Nutritional therapy must be adjusted for renal function and renal replacement therapy.

Renal replacement therapy is necessary when uremic symptoms develop or whenever extracellular volume excess, hyperkalemia, or metabolic acidosis is refractory to medical therapy. Various intermittent or continuous therapies are available to accomplish fluid removal (ultrafiltration) or solute removal (dialysis, hemofiltration, hemodiafiltration). An appropriate selection depends on the circumstances of the individual patient (especially hemodynamic status) and the resources available. Consultation with a nephrologist is advised to assist with determining the most appropriate treatment.

Key Points

Diagnosis and Management of Shock

- Shock is characterized by impaired tissue oxygenation and hypoperfusion.
- The four major categories of shock with characteristic hemodynamic patterns are hypovolemic, distributive, cardiogenic, and obstructive.

- The clinical manifestations of shock result from inadequate tissue oxygenation and perfusion, compensatory responses, and the syndrome's specific etiology.
- Interventions to restore perfusion center on achieving an adequate blood pressure, increasing cardiac output, optimizing the oxygen content of blood, and/or decreasing oxygen demand.
- The initial therapy for most forms of shock is replacement of intravascular volume with crystalloid or colloid solutions.
- The selection of a vasoactive agent to treat shock should be based on the hemodynamic effect desired for an individual patient and knowledge of the pharmacology of available agents.
- Reversible causes of acute oliguria or AKI should always be excluded, and intravascular volume should be optimized with crystalloid and/or colloid solutions.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Dabrowski GP, Steinberg SM, Ferrara JJ, et al. A critical assessment of endpoints of shock resuscitation. *Surg Clin North Am*. 2000;80:825-844.
2. Dellinger RP, Levy MM, Rhodes A, et al. Surviving Sepsis Campaign: International guidelines for management of severe sepsis and septic shock: 2012. *Crit Care Med*. 2013;41:580-637.
3. Gutierrez G, Reines HD, Wulf-Gutierrez ME. Clinical review: Hemorrhagic shock. *Crit Care*. 2004;8:373-381.
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5. Kidney Disease: Improving Global Outcomes (KDIGO) Acute Kidney Injury Work Group. KDIGO: Clinical practice guideline for acute kidney injury. *Kidney Int Suppl*. 2012;2:1-138.
6. Tharmaratnam D, Nolan J, Jain A. Management of cardiogenic shock complicating

acute coronary syndromes. *Heart*. 2013;99:1614-1623.

7. Vincent J-L, De Backer D. Circulatory shock. *N Engl J Med*. 2013;369:1726-1734.
8. Cecconi M, De Backer D, Antonelli M, et al. Consensus on circulatory shock and hemodynamic monitoring. Task Force of the European Society of Intensive Care Medicine. *Intensive Care Med*. 2014;40:1795-1815.
9. Myburgh JA, Mythen MG. Resuscitation fluids. *N Engl J Med*. 2013;369:1243-1251.

Suggested Websites

1. Kidney Disease: Improving Global Outcomes. www.kdigo.org.
2. Surviving Sepsis Campaign. www.survivingsepsis.org.
3. Society of Critical Care Medicine. www.SCCM.org.

NEUROLOGIC SUPPORT

Objectives

- Review the principles of primary and secondary brain insult and the common mechanisms of neuronal injury.
- Apply the concepts of intracranial hypertension and brain oxygen delivery and consumption to the management of the brain-injured patient.
- Review the clinical and diagnostic assessment of a brain-injured patient.
- List general treatments that are common in brain injury.
- Review specific management principles and options for selected pathophysiologic conditions.

Case Study

A 57-year-old woman is brought to the emergency department 80 min after the witnessed onset of aphasia and right hemiplegia. She has a history of hypertension and type 2 diabetes mellitus. Her current medications include aspirin and metformin. On examination, her blood pressure is 180/100 mm Hg, pulse 90 beats/min and regular, respiration 19 breaths/min, and temperature 37.2°C (98.9°F). She is alert but unable to speak or follow commands. Her cranial nerve exam shows a left conjugate gaze preference, absent movement of the right lower face with sparing of the forehead, absence of response to noxious stimuli on the right side of her face, and a diminished gag reflex on the right. She has a right hemiplegia and does not respond to noxious stimuli applied to the right side of her body. The remainder of her physical examination is unremarkable. An immediate computed tomography (CT) scan of the head is unremarkable.

– What type of primary brain injury is likely to be present?

– What are the immediate concerns?

– What interventions and monitoring should be instituted in addition to the CT scan?

I. INTRODUCTION

Primary injuries to the brain include ischemic events, trauma, hemorrhage, and anoxia, which may occur either in isolation or in combination. Mechanisms for these and other primary injuries are shown in **Table 8-1**.

Table 8-1	Common Mechanisms of Primary Brain Injuries

- Trauma: concussion, contusion, shear injury, penetrating injury, and diffuse axonal injury
- Ischemia: global (eg, cardiac arrest with anoxia) or regional (eg, vasospasm, compression of blood vessels, stroke)
- Inflammation: meningitis, encephalitis
- Compression: tumor, cerebral edema, hematoma (eg, epidural, subdural, or intraparenchymal)
- Metabolism: encephalopathies (eg, hepatic, electrolyte, drugs, toxins)

Often, little can be done to reverse the immediate and frequently devastating effects of the primary cerebral insult that produces neuronal injury or death. In some circumstances, the immediate effects of an injury may be reversed by prompt surgical intervention. As with the injury seen in myocardial infarction, many types of brain insults produce a region of maximum injury associated with a surrounding area of tissue, or penumbra, that may survive and recover if further damage can be prevented. Common mechanisms of secondary injury are shown in **Table 8-2**; these can also occur as primary injuries. The mechanisms of secondary brain injury may evolve over time from other primary insults. For example, edema after head trauma commonly produces secondary brain compression, vasospasm after subarachnoid hemorrhage may cause regional ischemia and stroke, or secondary hemorrhagic conversion after an ischemic stroke may induce compression and further ischemia.

Table 8-2	Common Mechanisms of Secondary Brain Injuries

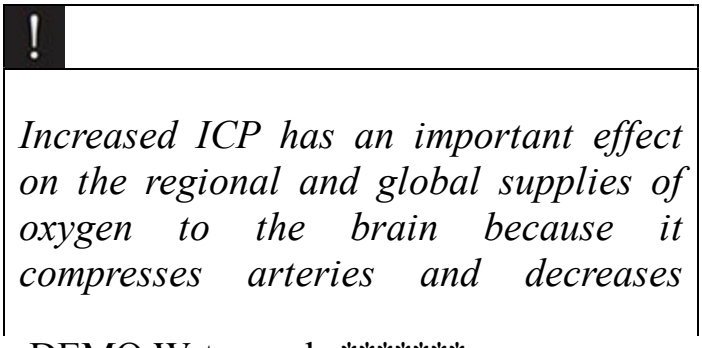
- Hypoperfusion: global (ie, secondary to high intracranial pressure, systemic arterial hypotension, or severe anemia) or regional (eg, secondary to high intracranial pressure, local edema, or vasospasm)
- Hypoxia: systemic hypoxemia, regional hypoperfusion, or high tissue consumption (ie, seizures, hyperthermia)
- Electrolyte or acid-base changes from systemic or regional ischemia
- Reperfusion injury with free radical formation

II. BRAIN INJURY MANAGEMENT PRINCIPLES

The focus of treatment for a neurologically compromised patient is the same as that for patients with other illnesses and injuries, that is, to ensure adequate oxygen delivery to meet the needs of both the damaged and the undamaged brain tissue. *The primary goal is prevention of secondary injury*. The initial care team must take early and aggressive action to ensure that secondary brain injury is prevented, minimized, or reversed with careful monitoring and treatment, particularly the prevention and early treatment of hypoxia and hypotension. Optimizing oxygen delivery to the brain requires attention to oxygenation, hemoglobin concentration, cardiac output, and blood pressure. Prevention and early treatment of fever, seizures, pain, agitation, and anxiety can minimize oxygen demands.

A. Intracranial Hypertension

Intracranial pressure reflects the balance of volume-control mechanisms within the noncompliant cranial compartment. Because the brain is enclosed within the rigid skull and relatively inflexible dura, with tissues and fluids that are incompressible, control of the different intracranial components is essential to maintain brain homeostasis, regulate intracranial pressure, and preserve cerebral perfusion. The critical compartment relationship depends on the volume occupied by each component. An increase in one component (eg, brain) must be accompanied by a decrease in another component (eg, blood). When the compensatory mechanisms are overwhelmed, intracranial pressure (ICP) increases and injury may ensue. In addition to the impaired cerebral perfusion, which may be a consequence of globally increased ICP, small pressure gradients within the skull may cause herniation of the brain around dural reflections (the falx and the tentorium), with shift of the midline structures. These movements within the skull may compromise function (eg, cause stupor or coma by disrupting the activity of the brainstem reticular formation) or lead to vascular compression and stroke.



cerebral blood flow.

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An intensivist or a neurosurgeon should be consulted if intracranial hypertension is suspected. The patient may need a catheter inserted into a lateral ventricle for monitoring and drainage of cerebrospinal fluid, or into the brain parenchyma for monitoring (**Table 8-3**). This monitoring includes intracranial pressure, temperature, and/or brain oxygen. Measurements of cerebral oxygenation require special equipment and expertise that are not available in most facilities. When direct measures are not available, the initial care team must treat based on the principles of oxygen supply and demand.

Table 8-3 Conditions Potentially Requiring Invasive Intracranial Pressure Monitoring

- Traumatic brain injury (**Table 8-6**)
- Acute subarachnoid hemorrhage with hydrocephalus, coma, or clinical deterioration
- Intracranial hemorrhage with intraventricular blood
- Large ischemic stroke
- Fulminant hepatic failure
- Global brain ischemia/anoxia with increasing edema

B. Hypoperfusion

Cerebral autoregulation reflects the normal arteriolar dilation or constriction that controls regional cerebral blood flow (CBF) and links oxygen demand to its delivery; thus, global CBF normally remains constant over a defined range of mean arterial pressures (MAP). Loss of autoregulation occurs in many pathologic conditions, and may lead to regional or global vasodilation and edema formation, which can further increase ICP. Increases in blood volume also profoundly affect the pressure inside the noncompliant cranial vault.

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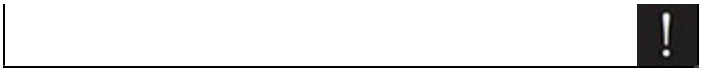
Although related, changes in CPP may not always result in similar changes in CBF.



CBF is usually evaluated by the cerebral perfusion pressure (CPP), which is the MAP (the driving pressure) minus the ICP (the pressure impeding blood flow):

$$CPP = MAP - ICP$$

The MAP must be measured at the same location as the ICP to be accurate; this is usually done by zeroing the arterial line transducer at the ear, and keeping it at the same height as the head when the head is elevated. The normal CPP is between 60 and 100 mm Hg. If the ICP increases without a change in MAP, CPP decreases, and CBF will also decrease if autoregulation has failed. The decrease in CBF increases the risk of brain ischemia. Clinicians should pay particular attention to changes in mental status, as these may indicate inadequate perfusion (among many other possibilities).

C. Recommendations for Therapy

To minimize damage to the brain, therapies are primarily designed to minimize oxygen demand and increase CBF and oxygen delivery. **Table 8-4** summarizes commonly accepted principles and therapeutic guidelines for treating a variety of brain insults and avoiding secondary brain injury. Note the focus on factors that minimize oxygen consumption and maximize oxygen delivery.

Table 8-4	General Principles of Managing Brain Injury

Prevent Abnormal Oxygen Demands

1. Avoid fever. Fever increases metabolic demand, resulting in neuronal injury and elevating intracranial pressure.
2. Avoid seizures. Prophylactic anticonvulsant administration is indicated after moderate or severe traumatic brain injury to prevent seizures in the first week, but the available evidence does not support longer use in head trauma or use in other neurologic injuries.
3. Avoid anxiety, agitation, or pain. Neuronal oxygen consumption may be decreased by an antianxiety agent, sedation, and analgesia.
4. Avoid shivering.
5. Minimize stimulation, particularly for the first 72 hours.

Promote Oxygen Delivery

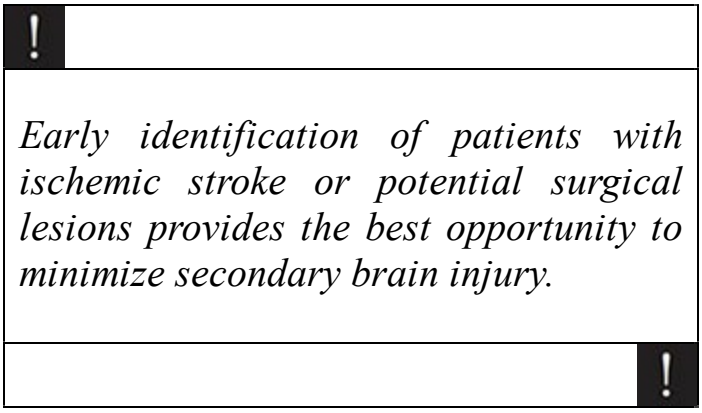
1. Ensure systemic oxygen transport with adequate oxygenation, hemoglobin concentration, and cardiac output.
2. Ensure optimal blood pressure. Many primary insults are associated with hypertension that may be a physiologic compensation or may be injurious. Elevated blood pressure may be undesirable in

patients with unsecured aneurysms and recent intracranial hemorrhage. *However, excessive lowering of blood pressure may result in secondary ischemia*.

3. Avoid prophylactic or routine hyperventilation because an increase in extracellular brain pH constricts responsive vessels and may reduce cerebral blood flow to ischemic zones. Brief hyperventilation while instituting other methods to lower elevated intracranial pressure may be lifesaving in the patient with evidence of herniation.
4. Ensure euvolemia because hypovolemia may result in systemic hypotension and hypoperfusion of brain tissue.
5. Rapid-sequence intubation should be used for patients with increased intracranial pressure. Consider administration of intravenous lidocaine or intravenous propofol to blunt the rise in intracranial pressure associated with intubation.
6. Institute nimodipine immediately in patients with aneurysmal subarachnoid hemorrhage.

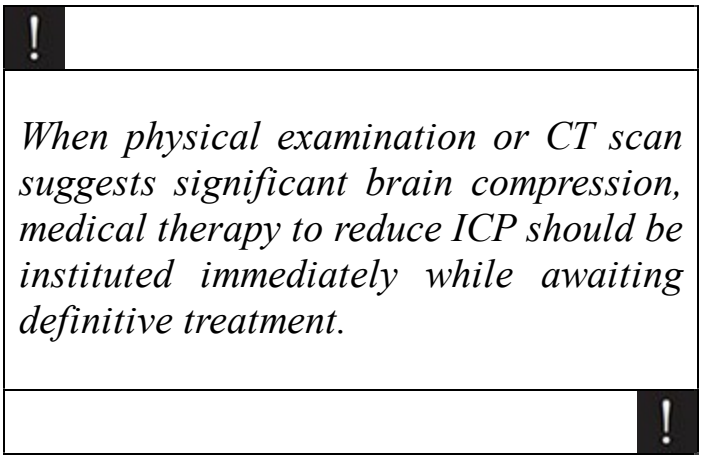
III. ASSESSMENT

After appropriate management of airway, breathing, and hemodynamic concerns, the priority in neurologic assessment is to distinguish among ischemic, structural, metabolic, and infectious injuries. Suspected ischemic stroke requires an immediate decision regarding thrombolytic therapy, and emergent neurologic consultation should be obtained. The presence of an expanding mass lesion accompanied by significant brain shift may indicate the need for immediate surgical evaluation and possible intervention. The most common causes of such an event include epidural, subdural, and intracerebral hematomas. Intracranial hematomas should be suspected in the settings of head trauma, recent neurosurgery, anticoagulant therapy, alcohol abuse, coagulopathies, and chronic or acute hypertension. The diagnostic procedure of choice, CT scan of the brain, characterizes the extent of structural injury. Medical treatment may be a temporizing option until more definitive therapy is available and implemented.



Serial examinations are necessary to detect the possible sequelae of many brain insults. Any change in the examination is a sensitive indicator of deterioration and should prompt an immediate and thorough reevaluation. For example, decreased consciousness

without lateralizing findings may be due to elevated ICP, hydrocephalus, fever, toxic ingestants, or worsening of an encephalopathy, among others.



When physical examination or CT scan suggests significant brain compression, medical therapy to reduce ICP should be instituted immediately while awaiting definitive treatment.

The Glasgow Coma Scale score is widely used in the initial and serial assessment of patients with head trauma, and it may be useful in evaluating patients with other brain insults. **Table 8-5** lists its components.

Table 8-5 Components of Glasgow Coma Scale Score

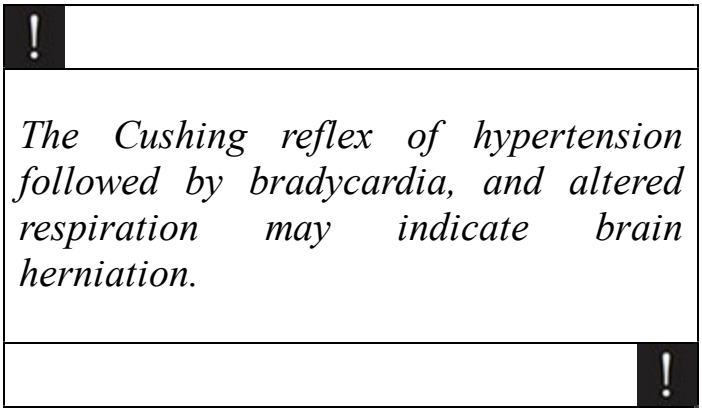
Clinical Parameters	Adults	Points
Eye opening	Spontaneous	4
	Response to speech	3
	Response to pain	2
	No response	1
Verbal response	Oriented and appropriate	5
	Disoriented and confused	4
	Inappropriate words	3
	Incomprehensible sounds	2
	No response	1
Best motor response	Obeys commands	6
	Localizes pain	5
	Withdraws from pain	4
	Flexor response	3
	Extensor response	2
	No response	1

Total Glasgow Coma Scale score = eye + verbal + motor scores; best possible score = 15, worst possible

score = 3.

Serial examinations, including evaluation of brainstem and cranial nerve function, should be performed. Pupillary asymmetry may be an important sign of horizontal shift of the brain, which commonly precedes downward herniation in patients with supratentorial masses. Disconjugate eye movements, a change in respiratory pattern, or deterioration in motor response may suggest an increase in intracranial mass effect and should be investigated immediately.

When clinical findings suggest herniation, emergent administration of mannitol or hypertonic saline should be initiated to lower ICP, and emergent neurosurgical assistance should be obtained. A brief period of hyperventilation may be considered. Whether repetition of an imaging study or immediate surgical therapy is required depends upon the nature, location, and progression of the pathologic process.



Neurosurgical consultation is advised for any patient who: (1) is at risk for developing an expanding intracranial mass lesion; (2) has an open or depressed skull fracture or acute ventricular obstruction; (3) demonstrates blood in the fourth ventricle, cerebellar bleeding, or subarachnoid hemorrhage; or (4) has cerebrospinal fluid leakage. Nontraumatic disease processes, such as spontaneous intracerebral hematoma, large brain tumors, or brain abscesses, require urgent neurosurgical consultation if clinical findings or an imaging study indicate significant mass effect (midline deviation, ventricular obliteration, brainstem or basal cistern compression).

Urgent neurosurgical consultation should be obtained for hemorrhages and infarcts in the posterior fossa regardless of the level of consciousness. Although such patients may have few findings on initial clinical examination, progressive swelling around the lesion may necessitate emergent surgical decompression. Typically, any cerebellar mass >3 cm in diameter with hydrocephalus or brainstem compression requires evacuation.

IV. SPECIFIC DIAGNOSES AND CONSIDERATIONS

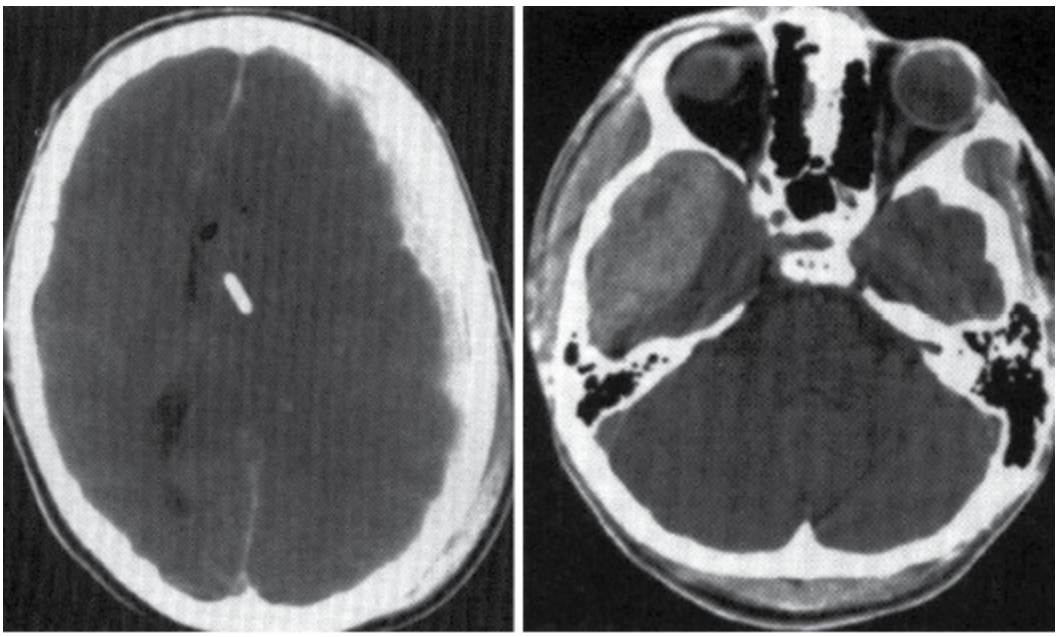
A. Traumatic Brain Injury

!
Cerebellar hemorrhage with altered consciousness is a surgical emergency.
!

Approximately 25% of patients who experience blunt head trauma require urgent evacuation of a subdural hematoma (**Figure 8-1A**) or an epidural hematoma (**Figure 8-1B**) to relieve compression of the brain. Neurosurgical consultation should be considered early. Because 20% of patients with severe traumatic brain injury will have concomitant cervical spinal cord injuries, immobilization of the cervical spine until it can be appropriately assessed is very important.

(left) Figure 8-1A. Subdural Hematoma

(right) Figure 8-1B. Epidural Hematoma



Penetrating and nonpenetrating head injuries are often associated with the formation of cerebral edema, brain contusions, or hemorrhage within the parenchyma. Because the skull cannot expand to accommodate increased intracranial volume and the

compensatory space in the subarachnoid space of the spinal canal is very limited, the ICP commonly becomes elevated. Monitoring and treatment of increased ICP are considered important in such patients.

Guidelines for the management of severe traumatic brain injury have been developed by the Brain Trauma Foundation on the basis of established evidence. These principles are included in the recommendations in **Table 8-6**.

Table 8-6 General Principles for Treatment of Traumatic Brain Injury

- Ensure the ABCs of resuscitation are performed.
- Avoid hypotension and maintain systolic blood pressure >90 mm Hg. It may be valuable to maintain mean arterial pressure higher than the mean arterial pressure associated with a systolic blood pressure of 90 mm Hg. Optimal mean arterial pressure is unknown.
- Avoid hypoxemia (Pa_{O_2} <60 mm Hg [8.0 kPa] or oxygen saturation <90%) while adequate oxygenation is maintained.
- Maintain alignment between head and trunk to avoid jugular compression.
- Keep the head of the bed at 30° to 45°elevation unless the patient is hypotensive. Elevation of the head promotes venous drainage and cerebrospinal fluid displacement to the spinal compartment. Adjust any devices that may constrict the neck, including cervical collars.
- Maintain the Pa_{CO_2} at 35 to 40 mm Hg (4.7-5.3 kPa). Prophylactic hyperventilation is not recommended. Hyperventilation is recommended as a temporizing measure for reduction of elevated intracranial pressure. Cerebral blood flow is often reduced in the first 24 hours after head trauma, and hyperventilation should be avoided in this period to prevent further reductions.
- Use normal saline as the primary maintenance fluid. Do not use hypotonic fluids.
- Actively treat fever to maintain body temperature at normal levels.
- Control harmful agitation with sedation if necessary. Use medications with a relatively short half-life to facilitate reliable and ongoing neurologic assessments.
- Maintain the usual electrolyte homeostasis and treat hyperglycemia/hypoglycemia.
- Assess and treat coagulation defects.
- Provide nutrition to attain full caloric replacements as tolerated.
- Prophylactic anticonvulsants are appropriate during the first week after traumatic brain injury.
- Give mannitol (0.25-1 g/kg IV push) or hypertonic saline (eg, 5-10 mL/kg of 3% NaCl as rapidly as possible) for signs of herniation or for neurologic deterioration not attributable to other factors. Expert consultation should be obtained if this type of hyperosmolar therapy is considered.
- Avoid steroid use. These agents are contraindicated in patients with head trauma.
- Initiate appropriate intracranial pressure monitoring:
    - For a patient with a Glasgow Coma Scale score between 3 and 8 after resuscitation or a score between 9 and 12 with an abnormal computed tomography scan
    - For a patient who has a normal computed tomography scan but at least two of the following

factors:

1. Age >40 years
2. Systolic blood pressure <90 mm Hg
3. Unilateral or bilateral motor posturing (decerebrate/decorticate)

- Maintain the lowest perfusion pressure compatible with adequate cerebral blood flow. The target cerebral perfusion pressure is in the range of 50 to 70 mm Hg, although patients with intact autoregulation may tolerate higher values. The ideal is the pressure that provides adequate cerebral perfusion and oxygenation while intracranial pressure is maintained <20 mm Hg.

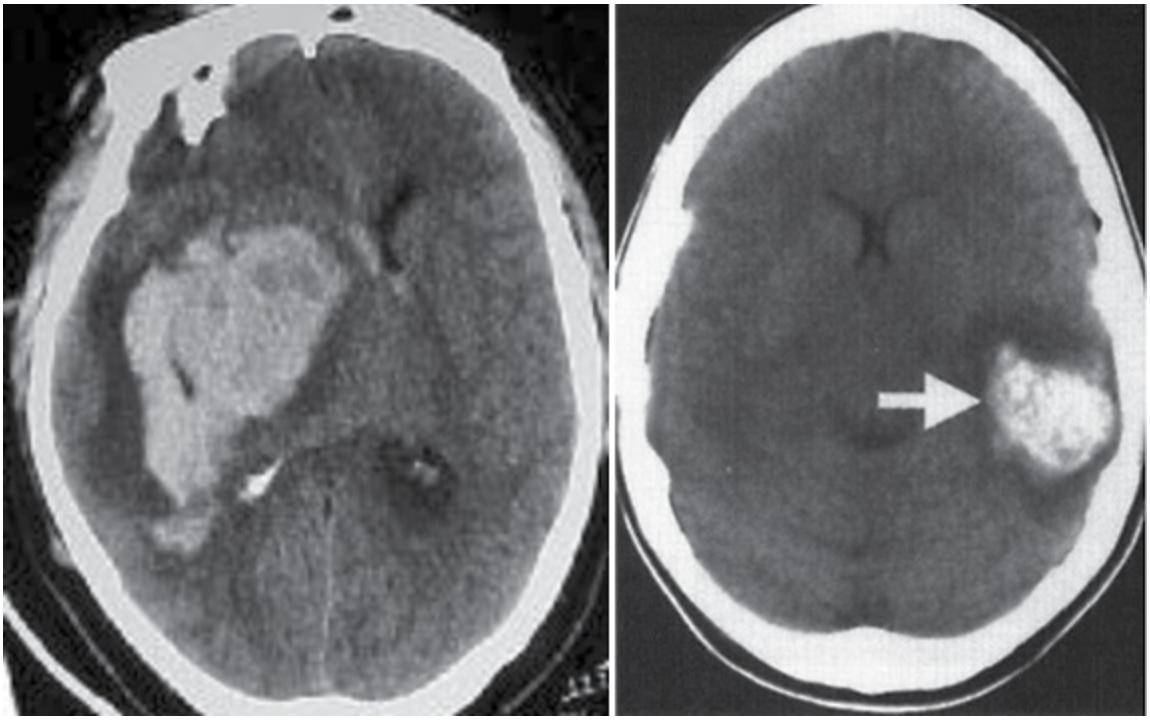
B. Intracerebral Hemorrhage

Patients with intracerebral hemorrhage frequently have a history of hypertension. Blood pressure control is controversial in these cases. Elevated blood pressure may contribute to rebleeding and edema formation but may also preserve regional CPP. Recent studies suggest that lowering the systolic blood pressure to 140 mm Hg may improve outcome. If elevated ICP is suspected, expert consultation is advised for assistance with blood pressure management. Preferred agents include labetalol and nicardipine. Use of vasodilators remains controversial, but drugs that cause substantial intracranial vasodilation (eg, nitroprusside, nitroglycerin) should be avoided.

Expansion of the hematoma occurs commonly, especially in patients taking anticoagulants or who have liver disease or low platelet counts. Some neurosurgeons may consider removal of the hematoma, especially in a young, clinically deteriorating patient with a large lobar hemorrhage or when the hemorrhage is associated with a surgically treatable lesion, such as an aneurysm, arteriovenous malformation, or cavernous angioma. Deep basal ganglionic hemorrhages do not yet have a commonly accepted surgical therapy (**Figure 8-2A**). Small hemorrhages may not require specific therapy (**Figure 8-2B**).

Figure 8-2A. CT Scan Demonstrating Large Right Basal Ganglion Intracerebral Hemorrhage with Midline Shift and Intraventricular Extension

Figure 8-2B. CT Scan Demonstrating Small Left Parietal Lobar Intracerebral Hemorrhage



C. Subarachnoid Hemorrhage

Characteristics from the patient history ("worst headache of their life") and CT findings usually confirm the diagnosis of subarachnoid hemorrhage (**Figure 8-3**). Classification systems (eg, the Hunt and Hess scale) have been used to categorize findings and suggest prognosis but do not alter the care provided by the primary team, as outlined in **Table 8-7**. Early aneurysm repeat rupture is frequently fatal, so initial therapy is aimed at decreasing its risk. Guidelines are available from the American Heart Association/American Stroke Association (AHA/ASA) and the Neurocritical Care Society. Prompt consultation with a center experienced in the care of these patients is essential. Almost all patients, regardless of severity, should be stabilized and evaluated for rapid transfer to such center for management.

Figure 8-3. CT Scan Demonstrating Subarachnoid Hemorrhage

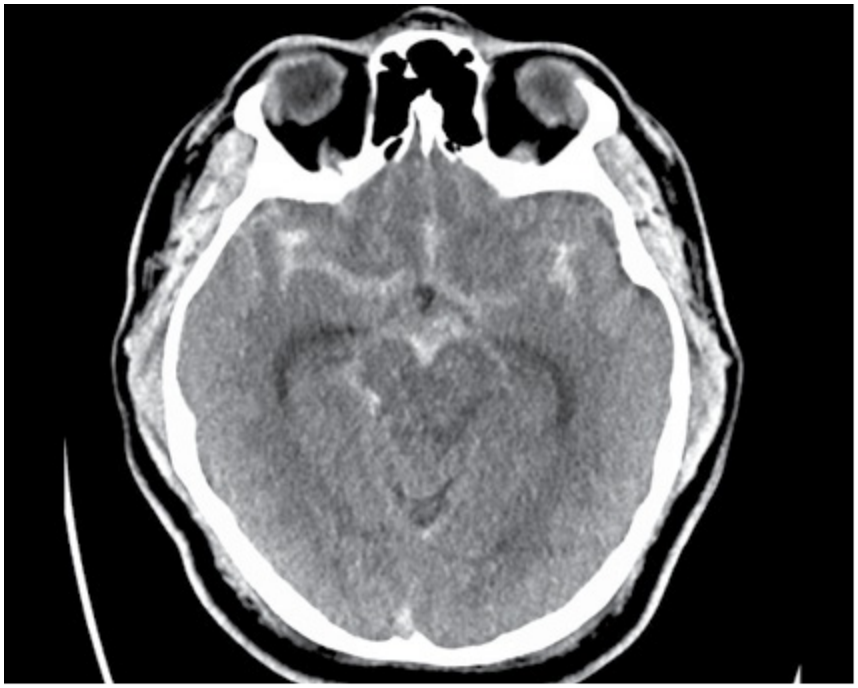


Table 8-7	Treatment of Subarachnoid Hemorrhage

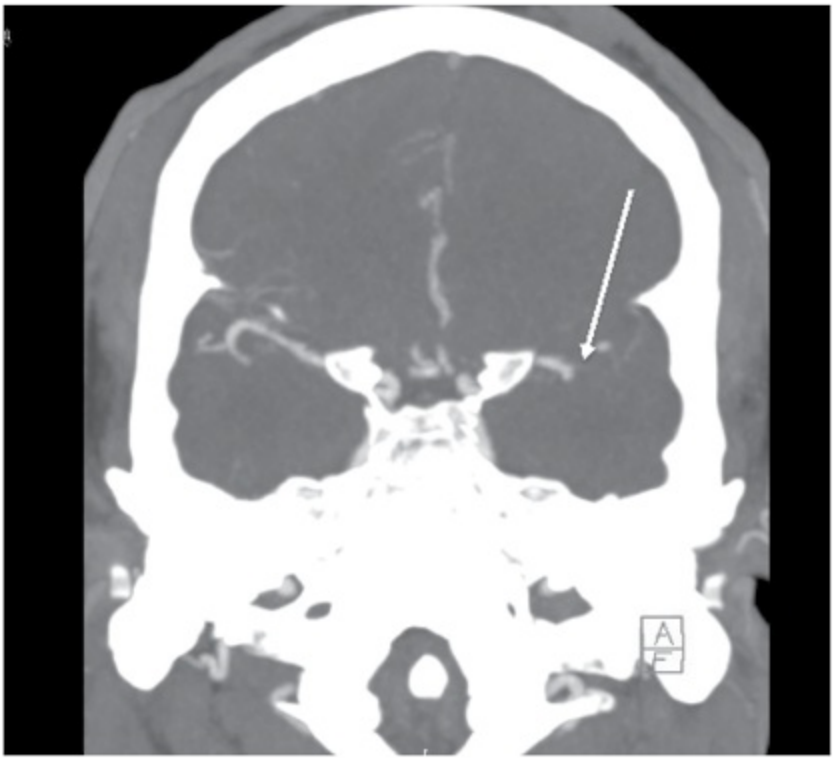
- Ensure the ABCs of resuscitation are performed.
- Control blood pressure early, before definitive surgical therapy. Rebleeding is the major early complication until the aneurysm is clipped or coiled. A variety of intravenous agents have been useful. Labetalol and nicardipine have been advocated. Nitroprusside should be avoided because of its tendency to induce cerebral vasodilation. Consider the effects of nimodipine on blood pressure when using other antihypertensive agents.
- Initiate oral nimodipine, 60 mg every 4 hours. (An intravenous preparation is available in some countries.) Hypotension should be avoided.
- Maintain euvolemia. Some advocate gentle intravascular volume expansion. Significant cardiac injury can occur as a result of catecholamine levels; thus, careful attention to arrhythmias and cardiac function is necessary.
- Avoid hyponatremia, which is commonly encountered. Normal saline should be used as the primary intravenous fluid. Hyponatremia usually reflects cerebral salt wasting rather than SIADH; cerebral salt wasting should not be treated with the volume restriction utilized for SIADH. Both groups of patients will have inappropriately high urine osmolality, so this marker cannot be used to indicate SIADH. If salt administration is indicated for cerebral salt wasting, small amounts of hypertonic saline may be necessary. Hyponatremia should be corrected slowly, as central pontine myelinolysis can occur from rapid and aggressive sodium correction.
- Perform rapid evaluation of the aneurysm location for surgical clipping or coiling, which requires urgent neurosurgical and/or neurointerventional radiology consultation.
- Manage patients in centers with the capacity for aneurysm clipping and coiling, and for vasospasm treatment.

Abbreviation: SIADH, syndrome of inappropriate antidiuretic hormone

D. Ischemic Stroke

Ischemic stroke usually occurs due to the thromboembolic obstruction of arteries. Administration of intravenous recombinant tissue plasminogen activator during the first 3 to 4.5 hours following the known onset of ischemic stroke substantially improves outcome in one-third of patients. For patients with larger artery occlusion (**Figure 8-4**), intra-arterial treatment with a stent-retriever device within 8 hours results in meaningful improvement in about 60% of patients.

Figure 8-4. CT Angiogram Demonstrating Occlusion of Left Middle Cerebral Artery (arrow)



Onset of symptoms, or the last time the patient was known to be at baseline, is the time used to determine whether a patient is a candidate for thrombolytic therapy. After an initial CT scan rules out the presence of hemorrhage, intravenous recombinant tissue plasminogen activator should be administered in a dosage of 0.9 mg/kg (10% as a bolus over 1 minute and 90% in a 1-hour infusion) for patients in whom treatment can be started within 4.5 hours. Personnel who are not familiar with the use of recombinant tissue plasminogen activator for the acute treatment of nonhemorrhagic stroke should seek immediate neurologic consultation before administering therapy. Intra-arterial clot retrieval is an important option for patients with large artery occlusion, regardless of whether recombinant tissue plasminogen activator has been administered. Guidelines are available from the AHA/ASA.

Supportive care includes management of hypertension. Although elevated blood pressure is often present early, a decrease in pressure usually occurs in the first hours after stroke without specific medical treatment. No evidence defines a level of blood

pressure that requires emergent intervention. The AHA/ASA have compiled consensus recommendations for patients who are candidates for thrombolytic therapy (**Table 8-8**). For those who are not candidates for thrombolysis, emergency administration of antihypertensive agents is not indicated unless the diastolic blood pressure is >120 mm Hg, systolic blood pressure is >220 mm Hg, or there is evidence of end-organ injury (eg, pulmonary edema). If treatment is indicated, the blood pressure should be lowered cautiously with a reasonable goal of lowering the pressure approximately 15% in the first 24 hours after stroke onset.

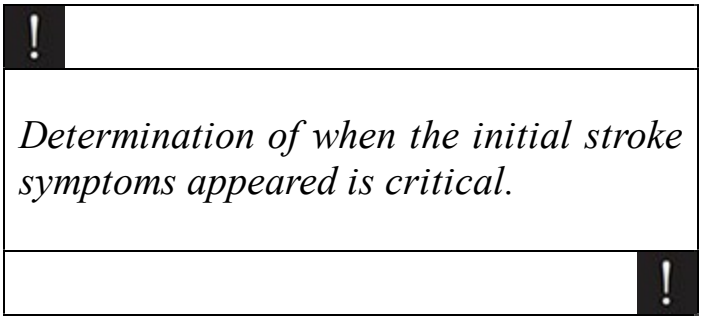


Table 8-8	Blood Pressure Management in Patients Eligible for Recombinant Tissue Plasminogen Activator Treatment[a]
Blood Pressure	**Treatment**
Pretreatment	
SBP >185 mm Hg or DBP >110 mm Hg	Labetalol 10-20 mg IV bolus (1-2 doses) Nicardipine infusion 5 mg/h titrated to goal BP (maximum 15 mg/h); reduce infusion to 3 mg/h when goal BP attained
Post-treatment	
SBP >230 mm Hg or DBP 121-140 mm Hg	Labetalol 10-20 mg IV bolus; may repeat every 10-20 min, maximum 300 mg Labetalol 10 mg IV bolus followed by infusion at 2-8 mg/min Nicardipine 5 mg/h IV infusion and titrate, maximum 15 mg/h
SBP 180-230 mm Hg or DBP 105-120 mm Hg	Labetalol 10 mg IV bolus; may repeat every 10-20 min to maximum 300 mg Labetalol 10 mg IV bolus followed by infusion at 2-8 mg/min

Abbreviations: SBP, systolic blood pressure; DBP, diastolic blood pressure; BP, blood pressure.
[a]Adapted with permission from Wolters Kluwer Health. Adams HP, del Zoppo G, Alberts MJ, et al. Guidelines for the early management of adults with ischemic stroke. *Stroke*. 2007;38:1655-1711.

Urgent anticoagulation with unfractionated or low-molecular-weight heparin is not indicated in acute stroke. Prophylactic heparin should be administered to immobilized patients to prevent venous thromboembolism, but the ideal time to start this therapy is not known. Aspirin administration within 24 to 48 hours of stroke onset is recommended for most patients after hemorrhage is excluded, but clopidogrel administration is not

recommended. Significant edema formation, typically within the first 72 hours, or extensive hemorrhage within the ischemic zone may indicate emergent hemicraniectomy.

E. Anoxic Injury

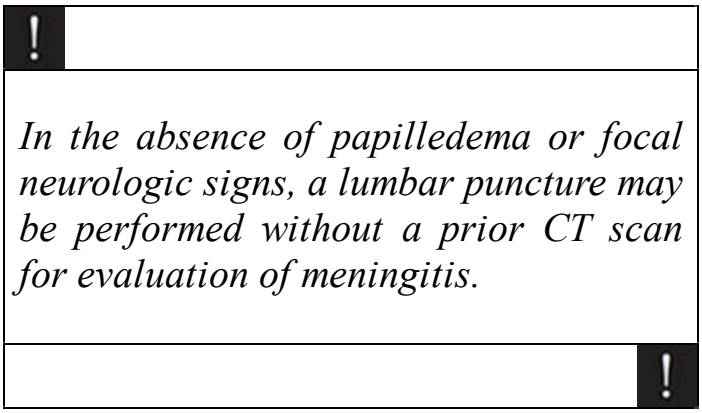
Relative anoxia may be a part of other injuries and may be due to airway loss, systemic hypoxemia, hypoperfusion, and other causes. Anoxia may also be the primary brain insult, as occurs during cardiac arrest. Neuronal damage may occur as a direct result of the primary insult of hypoxemia or hypoperfusion.

The initial team should maintain the usual standards of optimal oxygen delivery. Despite extensive studies of many agents and therapy options, none has proven selectively beneficial, nor has the poor prognosis from anoxic brain injury improved over time. Systemic cooling to 32°C or 36°C (89.6°F or 98.6°F) for 12 to 24 hours improves neurologic outcome in comatose patients after cardiac arrests. The inability to follow simple commands constitutes an acceptable threshold to consider cooling. Guidelines are available from the AHA and the International Liaison Committee on Resuscitation.

F. Metabolic Abnormalities, Infectious Emergencies, And Seizures

In adult patients with depressed consciousness after initial resuscitation, the use of 50% dextrose (50 mL intravenously) and thiamine (100 mg intravenously) should be considered for the treatment of potential hypoglycemia and the prevention of Wernicke encephalopathy if an immediate determination of the blood glucose concentration is not available. Intravenous naloxone should be administered if narcotic intoxication is a possibility. Other metabolic abnormalities, such as electrolyte disorders (ie, acute hyponatremia, hypercalcemia), liver failure, or uremia may also cause coma. Because headache or altered state of consciousness accompanied by fever, nuchal rigidity, and leukocytosis suggests meningitis or encephalitis, the cerebrospinal fluid should be submitted for physical, chemical, and bacteriologic (culture and Gram stain) studies. If clinical examination suggests a mass lesion or elevated ICP, a CT scan should be performed before lumbar puncture. If the scan reveals evidence of mass effect or generalized cerebral edema, a lumbar puncture may precipitate a herniation syndrome and should be postponed. When infection is part of the differential diagnosis, appropriate antibacterial and antiviral treatment should be initiated before performing the imaging study because early therapy for bacterial meningitis or encephalitis may be lifesaving. Blood cultures should be obtained before antibiotic therapy unless this would delay treatment. Antibiotics should also be given if lumbar puncture is delayed for any other reason. Treatment recommendations for adults are outlined in **Chapter 11**

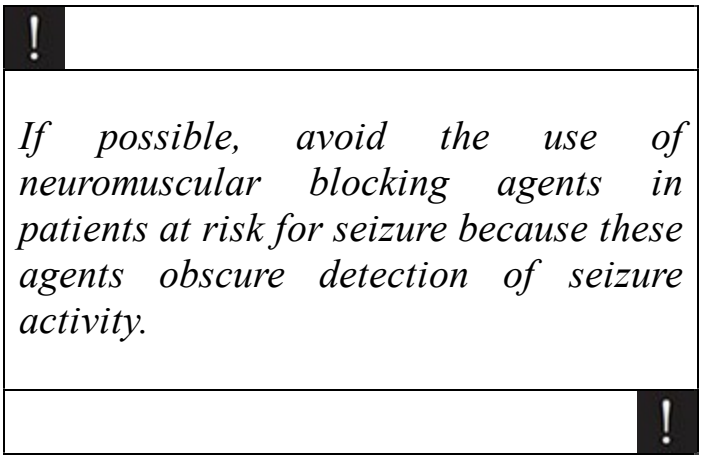
and those for children are in **Chapter 16**.



In the absence of papilledema or focal neurologic signs, a lumbar puncture may be performed without a prior CT scan for evaluation of meningitis.

Seizure activity after an acute brain injury increases cerebral oxygen requirements and typically elevates the ICP. Appropriate therapy should be administered to terminate seizure activity as soon as possible. The intravenous administration of anticonvulsants, many of which have a potent sedative effect, may depress respiratory function and requires appropriate supportive therapy. In addition, hypotension may occur, requiring additional intravenous fluids and/or vasopressors to preserve MAP and CPP.

Intravenous benzodiazepines are administered at the onset of prolonged or repeated seizure activity. Status epilepticus requires emergent neurologic consultation, and lorazepam 0.1 mg/kg should be administered intravenously. Intramuscular midazolam, 0.15 mg/kg, is an alternative if intravenous access is not immediately available. Anticonvulsants used in refractory status epilepticus include propofol (3 mg/kg loading dose, then infusion of 1-5 mg/kg/h) or midazolam (0.2 mg/kg loading dose, then infusion of 1-20 µg/kg/min) with electroencephalography and other ICU monitoring. After stabilization, loading with phenytoin or fosphenytoin may be appropriate to prevent recurrent seizures.



If possible, avoid the use of neuromuscular blocking agents in patients at risk for seizure because these agents obscure detection of seizure activity.

G. Spinal Cord Injury

Cervical spine injury in awake patients is usually apparent from neck pain and weakness. If awareness is impaired, suspect cervical spinal cord injury in patients with respiratory weakness, extremity weakness without facial weakness, hypotension with bradycardia, and difficulty maintaining normothermia. Patients with lesions below C4 may breathe adequately on presentation but could progress to abrupt respiratory failure and thus must never be left unmonitored.

Thoracolumbar spine injury spares the upper extremities but involves leg weakness; depending on the level, the patients may have hypotension with tachycardia or unusual swings in blood pressure.

Initial management includes immobilization (cervical collar, backboard) while obtaining emergent neurosurgical consultation. However, patients should not be left on backboards after arrival in the emergency department. Use of methylprednisolone is controversial and should be discussed with the consultant.

CT scans of the spine can be obtained without removing immobilizing devices.

H. Other Neurologic Causes of Acute Respiratory Failure

Patients with conditions causing global weakness, such as myasthenia gravis and the Guillain-Barré syndrome, may have problems maintaining upper airway patency and clearing secretions in addition to respiratory muscle weakness. In such patients, endotracheal intubation may be needed for airway protection before being mandated by the falling tidal volume. Measurement of vital capacity and negative inspiratory pressure is important. Patients with <20 mL/kg vital capacity should be moved to an ICU and will likely need intubation soon. One should intubate based on tachypnea and discomfort without waiting for an elevation of $Paco_2$. Hypoxia due to atelectasis in patients with adequate airway protection may be treated with continuous positive airway pressure. A neurologist should be consulted when the diagnosis is suspected, as treatment with intravenous immunoglobulin or plasma exchange may slow or halt disease progression and speed recovery.

Autonomic dysfunction is common in the Guillain-Barré syndrome and may lead to large and rapid swings in blood pressure and heart rate requiring intravenous therapy.

I. Brain-death Criteria and Organ Donation

Despite the best efforts of medical and surgical teams, massive injury, cerebral infarction, or hemorrhage may result in a loss of all cerebral and brainstem functions. Evaluation of brain death and the guidelines for organ donation are variable, depending on the country, state, and facility. For more information about brain death and organ donation, see **Appendix 6**.

Key Points

Neurologic Support

- Brain injury occurs as a consequence of a primary insult and secondary injury. The prevention of secondary brain injury is a critical goal for the initial care team.
- The most significant mechanisms for secondary injury in brain-injured patients are hypotension and hypoxia.
- Optimizing oxygen delivery while controlling oxygen consumption is a general treatment principle for all types of brain injury.
- Important principles/guidelines for initial treatment apply to all types of primary brain injury and help prevent harmful secondary sequelae.
- Blood pressure management is dependent on the initial brain injury. However, excessive lowering of blood pressure in any acute brain injury may induce secondary ischemia.
- Avoid prophylactic or routine hyperventilation in patients with brain injuries. Mannitol should be given and hyperventilation initiated for signs of herniation or if neurologic deterioration is not attributable to other factors.
- Ensure euvolemia using normal saline as the primary maintenance fluid.
- Seizure activity after acute brain injury should be terminated with an intravenous dose of a benzodiazepine, followed by an intravenous loading dose of phenytoin or fosphenytoin.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Bleck TP. Bacterial meningitis and other nonviral infections of the nervous system. *Crit Care Clin*. 2013;29:975-987.

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8. Connolly ES, Rabenstein AA, Carhuapoma JR, et al. Guidelines for the management of aneurysmal subarachnoid hemorrhage: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. *Stroke*. 2012;43:1711-1737.

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17. Silbergleit R, Durkalski V, Lowenstein D, et al. Intramuscular versus intravenous therapy for prehospital status epilepticus. *N Engl J Med*. 2012;366:591-600.

18. Torbey MT, Bösel J, Rhoney DH, et al. Evidence-based guidelines for the management of large hemispheric infarction: a statement for health care professionals from the Neurocritical Care Society and the German Society for Neurointensive Care and Emergency Medicine. *Neurocrit Care*. 2015;22:146-164.

19. Vahedi K, Hofmeijer J, Juettler E, et al. Early decompressive surgery in malignant infarction of the middle cerebral artery: a pooled analysis of three randomised controlled trials. *Lancet Neurol*. 2007;6:215-222.

20. Walters BC, Hadley MN, Hurlbert RJ, et al. Guidelines for the management of acute cervical spine and spinal cord injuries: 2013 update. *Neurosurgery*. 2013;60 (Suppl 1):82-91.

Suggested Websites

1. Society of Critical Care Medicine/Guidelines. www.SCCM.org.
2. Brain Trauma Foundation. http://www.braintrauma.org.
3. Brain Attack Coalition. http://www.stroke-site.org.
4. Neurocritical Care Society. http://www.neurocriticalcare.org.

Basic Trauma and Burn Support

Objectives

- Prioritize and initiate a timely assessment of the traumatized patient.
- Initiate treatment of life-threatening traumatic injury.
- Utilize radiography in identifying significant traumatic injury.
- Identify and respond to significant changes in the patient's status after traumatic injury.
- Initiate early burn management.
- Review indications for initiating surgical consultation and/or transferring the patient to a higher level of care.

Case Study

A middle-aged man has been brought to the emergency department after his car collided with a large truck. He was not wearing a seat belt and was ejected. He is making incoherent sounds and is unable to clear his oral secretions. He has an open femur fracture with hemorrhage, and contusions are present over the left chest wall and upper quadrant of the abdomen. Vital signs include a blood pressure of 90/60 mm Hg, pulse rate of 125 beats/min, and respiratory rate of 35 breaths/min.

The patient is lethargic but moves all extremities voluntarily. His skin is cool and clammy.

– What does the primary survey indicate?

– What are the most urgent initial interventions?

I. INTRODUCTION

It is not the intention of the FCCS program to replace the Advanced Trauma Life Support (ATLS) course provided by the American College of Surgeons. The material presented here is intended to highlight evaluation and treatment issues for the provider confronted with a deteriorating patient in the setting of injury. Care providers who regularly encounter patients with traumatic injuries are encouraged to enroll in an ATLS course or obtain other similar training.

A. Death Following Injury

In the United States, traumatic injuries remain the leading cause of death in individuals aged 1 to 44 years. Death due to injury occurs in one of three periods. The first period is within seconds to minutes of injury, when deaths generally result from severe brain or high spinal cord injury, loss of the airway, or rupture of the heart, aorta, or other large blood vessels. Few of these patients can be salvaged because of the severity of injury, and prevention is the only way to reduce such trauma-related deaths. The second period occurs within minutes to hours following injury; these deaths are usually due to subdural and epidural hematomas, hemopneumothorax, solid organ rupture (spleen or liver), pelvic fractures, or other injuries associated with blood loss. The "golden hour" after trauma is characterized by the need for rapid assessment and resolution of these injuries. The third period occurs days to weeks after the initial injury and is most often due to sepsis with associated multiple organ failure.

Three principles guide the approach to injury. The most important is that the greatest threat to life must be treated first. The second premise is that it is not necessary to establish a definitive diagnosis before beginning lifesaving treatment. The third is that a detailed history is not essential to begin care in the setting of acute injury.

II. Trauma Management

Early management of the seriously injured patient requires simultaneous evaluation and treatment. The first goal is to ensure adequate oxygen delivery to vital organs by following an established sequence of priorities that allows identification and treatment of injuries causing immediate threats to life (primary assessment). Patient management should begin with the rapid primary evaluation and simultaneous resuscitation of vital functions, followed by a more detailed secondary assessment (head-to-toe examination), and finally, the initiation of definitive care. This process begins with the ABCDE of

trauma care, which guides the identification of life-threatening conditions through the initial assessment sequence of airway, breathing, circulation, disability, and exposure (**Table 9-1**).

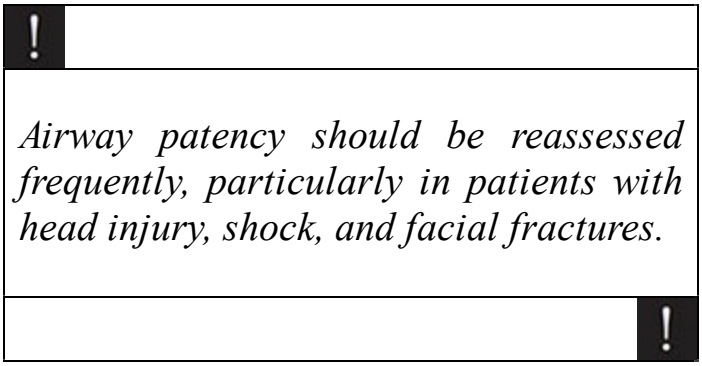
Table 9-1	Initial Assessment of Trauma
Airway: maintenance with cervical spine precautions **B**reathing: ventilation and oxygenation **C**irculation: hemorrhage control **D**isability: brief neurologic examination **E**xposure/environment: clothing removed, avoiding hypothermia	

A surgeon skilled in trauma management should be consulted early in the course of all serious trauma cases. Routing trauma patients to a center with trauma surgeons is crucial in the survival of the victims. When a surgeon is not immediately available or when the patient is awaiting transfer, evaluation (tertiary assessment) and intervention should continue.

A. Primary Assessment: Initial Evaluation and Resuscitation

1. Airway and Breathing

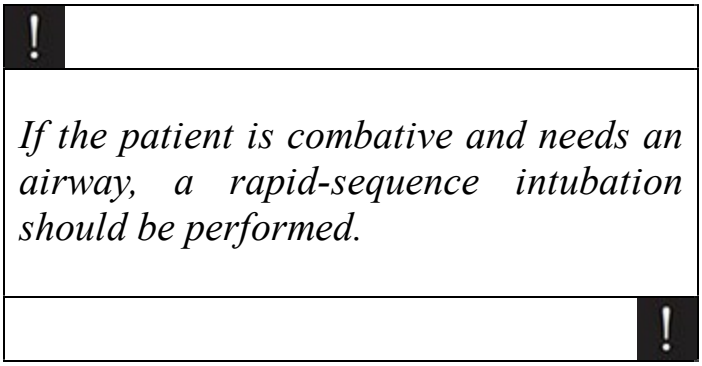
If the patient is able to communicate verbally, the airway is unlikely to be in immediate jeopardy; however, repeated assessment of airway patency is essential. Patients with severe head injury (Glasgow Coma Scale [GCS] score of 8 or less) usually require placement of a definitive, protective airway. Nonpurposeful motor responses support the need for immediate airway management.



The airway should first be assessed for patency. Assessment for signs of airway obstruction includes inspection for foreign bodies and facial, mandibular, or tracheal/laryngeal fractures that may result in airway obstruction. Patients can develop

signs of airway obstruction after benign initial presentation. Profuse bleeding from an oropharyngeal injury may warrant a definitive airway placement.

After blunt trauma, airway control should proceed on the assumption that an unstable fracture or ligamentous injury of the cervical spine (C-spine) exists. Airway patency must be established, supplemental oxygen provided, and adequacy of ventilation ensured, as discussed in **Chapter 2**. If active airway intervention is needed before evaluation for possible C-spine fracture, the technique chosen for airway control (intubation, adjunctive device, or surgical airway) should take into account the expertise of available personnel, type of equipment available, patient factors, and injuries. If the patient is apneic or deteriorating rapidly, effective bag-mask ventilation can be lifesaving. Standard orotracheal intubation should be attempted with the use of in-line manual stabilization of the head and neck. Proper in-line stabilization may be accomplished from the front or the side of the patient. One care provider supports the occiput and mandible with both hands to maintain neck alignment without applying traction or distraction. With secure stabilization, the anterior portion of the cervical collar may be removed to allow airway interventions. In-line stabilization is continued until the cervical collar is replaced and the endotracheal tube or other airway device is secured. If an airway cannot otherwise be secured, a laryngeal mask airway, esophageal-tracheal double lumen airway device, or surgical cricothyrotomy is indicated.



If the patient is combative and needs an airway, a rapid-sequence intubation should be performed.

a. Key Issues in Airway Control

Facial fractures are not an immediate priority unless heavy bleeding or uncontrollable secretions are present. Similarly, facial fractures usually do not require that the patient be intubated. Mandibular fractures, however, are more likely to be associated with soft-tissue injury that may compromise the airway. Care should be taken to avoid nasotracheal intubation in patients with suspected midface and basal skull fractures.

A cricothyrotomy should be avoided when tracheal/laryngeal disruption is suspected.


Further details regarding advanced airway management can be found in **Chapter 2**.

b. Key Injuries

While many injuries can eventually effect the ability to ventilate and oxygenate, several important injuries need to be urgently identified and managed.

Pneumothorax is frequently associated with rib fractures and can require chest tube placement. Any patient who has a pneumothorax on plain chest films and is receiving general anesthesia should have a chest tube in place. Tension pneumothorax should be evaluated and treated (**Chapter 5**). Open pneumothorax is generally associated with soft-tissue loss requiring dressing closure and chest-tube placement. Massive hemothorax is suggested by physical examination and chest radiograph. Immediate evacuation of more than 1500 mL of blood after placement of a chest tube or ongoing blood loss of >200 mL per hour for 2 to 4 hours is an indication for thoracotomy.

Rib fractures are often missed on a chest radiograph; however, a fracture may be suspected and documented when tenderness over the fracture is identified during physical examination. Pain control may be required to ensure adequate spontaneous ventilation. Flail chest resulting from segmental rib fractures is manifested by paradoxical movement of the involved portion of the chest wall (ie, inward movement of the segment during inhalation). Flail chest is also associated with contusion of the underlying lung, pain, and hypoxemia.

2. Circulation

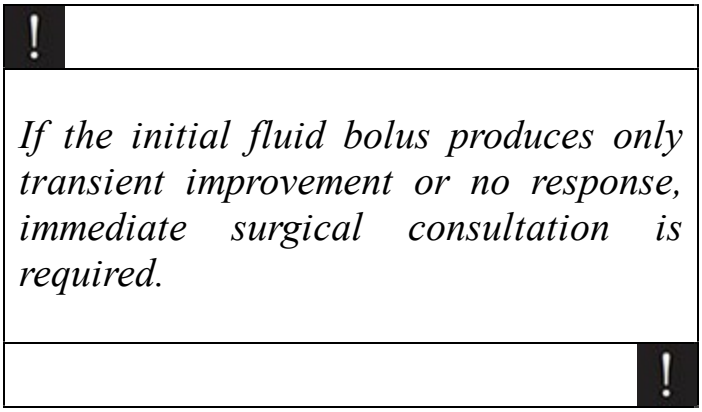
Case Study

A young man arrives in the emergency department with an epigastric stab wound, but the character of the weapon is unknown. Presenting systolic blood pressure is 90 mm Hg and the patient is tachycardic. His systolic blood pressure improves (>100 mm Hg) with administration of intravenous fluids but deteriorates when bolus fluids are stopped. Extremities are cool and the patient is anxious.

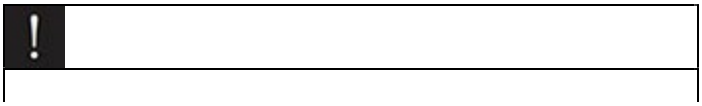
– Is this patient in shock?

– What is the primary concern?

– What therapy is recommended?



The leading cause of shock in a trauma patient is hemorrhage. Initial empiric treatment in adults consists of isotonic crystalloid infusion (2 L of warmed lactated Ringer or normal saline solution) via two large-bore peripheral intravenous catheters and control of external hemorrhage by means of manual compression. Targets for empiric fluid therapy are normalization of blood pressure, reversal of tachycardia, and maintenance of adequate organ perfusion (**Chapter 7**). Patients with no traumatic brain injury, but extensive hemorrhage that may require operative intervention, are better managed by resuscitation with permissive hypotension to a systolic blood pressure of 90 to 100 mm Hg until operative control of the hemorrhage can be accomplished. This supports control of vessels that may have thrombosed and are not presently bleeding, but that may re-bleed if the blood pressure is normalized. When hypoperfusion and vascular compensation limit peripheral access, cannulation of a central vein (ideally with a 7F, 8.5F, or 9F introducer) is an alternative, as is intraosseous access. Concomitant diagnostic studies for the source of bleeding can include chest radiographs (hemothorax), pelvic radiograph (pelvic fracture, open-book or vertical pelvic shear injury), focused assessment sonography in trauma (FAST), or diagnostic peritoneal lavage (DPL) [intraperitoneal hemorrhage]. If the patient is hemodynamically stable, a computed tomography (CT) scan of the abdomen and pelvis may be performed to better delineate the injuries unless a definitive indication to operate is present. A hemodynamically unstable patient should not be moved for CT scanning. Immediate control of external hemorrhage should proceed simultaneously with rapid resuscitation. In trauma to an extremity, direct pressure is recommended. Blind clamping at bleeding vessels is discouraged to avoid potential injury to adjacent structures.



It is critical not to equate the absence of hypotension with the absence of shock. Patients may have significant blood loss (Class I or II shock) without a change in blood pressure.

As shown in **Table 9-2**, a patient's systolic blood pressure, heart rate, respiratory rate, and mental status can be used to assess blood loss. The American College of Surgeons also validates a decrease in pulse pressure as a sign of occult hypoperfusion. Circulating blood volume corresponds to 7% of normal body weight (70 mL/kg) in an adult and 8% to 9% of normal body weight (80-90 mL/kg) in children. Blood loss up to 1,200 mL may occur in a normotensive adult (70 kg) with minimal tachycardia. Class II hemorrhage is uncomplicated shock, but crystalloid resuscitation may be sufficient. Class III hemorrhage requires crystalloid resuscitation and often blood replacement. Class IV hemorrhage can be considered preterminal and requires aggressive measures to restore intravascular volume and red blood cell mass and to control bleeding. Treatment should be directed by the initial response to therapy rather than by a classification scheme. Patients will respond to fluid resuscitation in one of three ways. One group of patients will regain normal vital signs with small volumes of fluid. A second group of patients will initially respond to the fluid resuscitation, but then demonstrate signs of hemodynamic deterioration with time or a decrease in the fluid resuscitation; they will require additional fluids and focused evaluation of the etiology and treatment of the injuries. This transient response is suggestive of ongoing hemorrhage. The third group of patients will not show signs of physiologic improvement despite volume resuscitation; these patients often need immediate operative intervention. They likely have ongoing major hemorrhage. Without rapid and aggressive intervention, their mortality will be high.

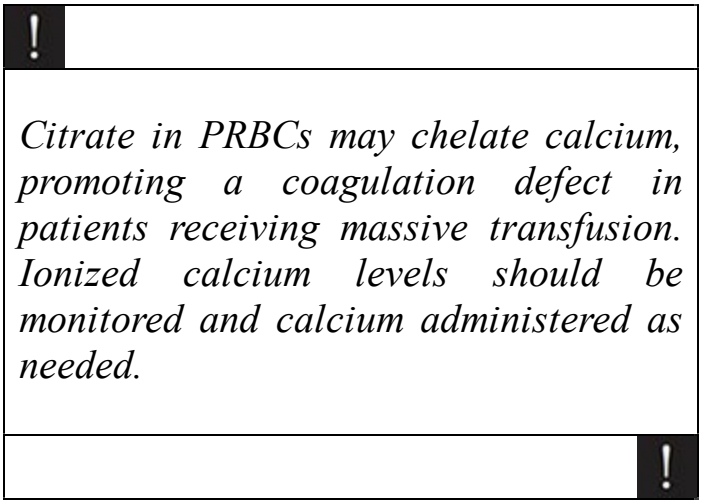
Table 9-2 Hemorrhage Classification[a]

	Shock Class			
	I	**II**	**III**	**IV**
Blood loss (mL)[b]	Up to 750	750-1500	1500-2000	>2000
Blood loss (% blood volume)	Up to 15%	15%-30%	30%-40%	>40%
Pulse (beats/min)	<100	100-120	120-140	>140
Systolic blood pressure (mm Hg)	Normal	Normal	Decreased	Decreased

Pulse pressure	Normal or increased	Decreased	Decreased	Decreased
Respiratory rate (breaths/min)	14-20	20-30	30-40	>35
Urine output (mL/h)	>30	20-30	5-15	Negligible
Mental status	Slightly anxious	Mildly anxious	Anxious, confused	Confused, lethargic
Resuscitation fluid	Oral or crystalloid	Crystalloid	Crystalloid and blood	Blood and crystalloids

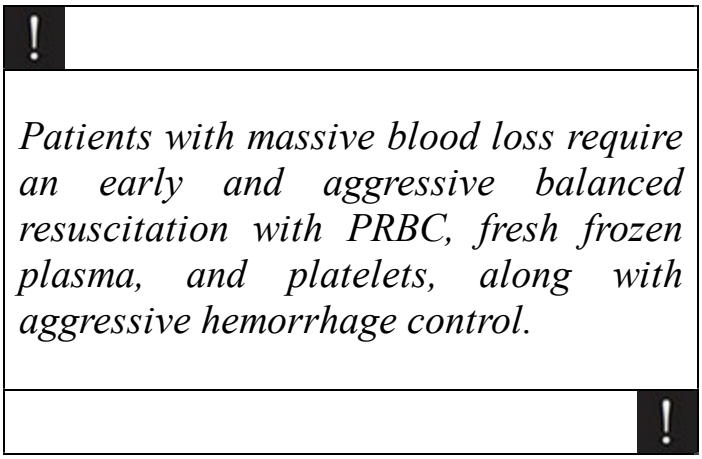
[a]Adapted with permission from the American College of Surgeons. American College of Surgeons Committee on Trauma. *Advanced Trauma Life Support for Doctors (ATLS): Student Course Manual*. 9th ed. Chicago, IL: American College of Surgeons; 2012.
[b]For 70-kg man.

When beginning resuscitation for patients in shock, isotonic crystalloid can be used. However, the volume should be controlled and minimized to no more than 1 or 2 L. If there is an inadequate physiologic response, this should be followed by the early administration of packed red blood cells (PRBCs). Fully crossmatched blood is rarely available for emergency trauma resuscitation. Uncrossmatched type-specific blood can be safely administered and is available in many hospitals within 15 to 20 minutes after a request is received. If type-specific blood is not available and the patient is unstable, O-negative PRBCs should be used. In most trauma centers, uncrossmatched blood is almost immediately available in the trauma resuscitation area for use in the unstable trauma patient.



In situations where massive transfusion is anticipated or probably likely, the early use of a balanced resuscitation using a combination of PRBCs, fresh frozen plasma, platelets, and cryoprecipitate should be strongly considered. In these situations, the most urgent priority is control of ongoing hemorrhage. Typically this involves operative intervention; however, with certain injuries−especially severe pelvic fractures with ******ebook converter DEMO Watermarks*******

active bleeding into a pelvic hematoma−other interventions, such as angiography with embolization, can be lifesaving. Many trauma centers have a massive transfusion protocol in place to allow the rapid procurement of blood products for administration in the critically injured, unstable, massively bleeding patient. Developing evidence suggests that the administration of crystalloid solutions should be minimized, especially in this population. There is also increasing evidence that the use of ratio-based blood product resuscitation (PRBCs, fresh frozen plasma, and platelets close to a 1:1:1 ratio) improves outcomes and may decrease the physiologic insult to these critically ill patients. Ratio-based resuscitation likely provides some of the same benefits as the use of fresh whole blood and may be helpful in minimizing the coagulopathy that can develop in the massively injured.



3. Disability/Exposure

Rapid neurologic evaluation is performed in the emergency department and includes determination of level of consciousness, pupillary size and reaction, lateralizing signs, and level of spinal cord injury. The GCS score is a quick, simple method for determining the level of consciousness and is predictive of outcome (particularly the best motor response). A decrease in the level of consciousness may reflect decreased cerebral perfusion or may be due to direct brain injury. Hypoglycemia, ethanol, narcotics, and other drugs may also be involved. An altered level of consciousness indicates the need for immediate reevaluation of oxygenation, ventilation, and tissue perfusion. Changes in consciousness should be assumed to be due to intracerebral conditions until proven otherwise. If the patient's condition permits, a good exam prior to sedation and intubation is essential to determine the presence of any localizing intracranial or spinal cord injury.

Throughout the initial resuscitation period, efforts should be made to control and prevent hypothermia. Patients are often hypothermic after environmental exposure, and the body temperature may fall further after administration of room temperature

resuscitation fluids and cold blood, removal of clothing for examination purposes, loss of normal temperature-regulating reflexes in shock, or the use of some medications. Hypothermia contributes to coagulation abnormalities, cardiovascular collapse, and poor outcome, and so should be avoided and treated. Warm intravenous fluids, heated respiratory gases in mechanical ventilation, warm rooms, insulating covers, and heat lamps can be used.

4. Monitoring

Improvements in parameters such as heart rate, blood pressure, pulse pressure, respiratory rate, acid-base status, body temperature, and urinary output are the best guides to adequacy of resuscitation. Evaluation begins during the initial survey and should be repeated frequently. Pulse oximetry is a valuable adjunct for monitoring hemoglobin saturation with oxygen in injured patients, but it is not useful for evaluating the adequacy of ventilation. Blood pressure, as the sole marker of resuscitation, may be a poor measure of actual tissue perfusion. Additional metabolic markers, such as serum lactate, base deficit, and pH, will assist in the determination of the adequacy of resuscitation. Perfusion of extremities may be evaluated by examining capillary refill and hematoma formation, as well as the presence of the peripheral pulses.

A urinary catheter should be inserted as soon as is practical to monitor urine output as a gauge of renal perfusion, although it must be used with caution in male patients when urethral injury is suspected (eg, blood at the urethral meatus, scrotal hematoma, or abnormal prostate on rectal exam). In these cases, a retrograde urethrogram can be used to rapidly evaluate for urethral injury.

5. Hemorrhagic Shock

As resuscitation proceeds, it is crucial to identify potential causes of hypotension. A search for occult blood loss should be undertaken after any external hemorrhage is controlled. The most frequent sites for such blood loss are the chest, abdomen, pelvis, and the soft tissues adjacent to long bone fractures.

a. Hemothorax

A chest radiograph (ideally with the patient in upright or reverse Trendelenburg position if hemodynamically stable) is a reliable screen for intrathoracic bleeding. Ultrasonography of the chest also may reliably detect hemothorax or pericardial fluid.

Hemothorax should be drained promptly by chest tube placement, with a subsequent radiograph to verify the location of the chest tube, blood evacuation, and lung expansion. As noted earlier, rapid loss of 1500 mL of blood upon chest tube insertion or

continued losses of >200 mL/h for 2 to 4 hours may necessitate thoracotomy. If available, autotransfusion devices should be attached to any chest tube drainage canister placed for massive hemothorax.

b. Intra-abdominal Hemorrhage

Abdominal examination is often misleading in the detection of acute bleeding, especially in patients with lower chest trauma, rib fractures, spinal cord injury, intoxication, or altered level of consciousness. Any patient who has sustained significant blunt torso injury from a direct blow or deceleration, or a penetrating torso injury must be considered to have an abdominal visceral or vascular injury. Focused ultrasound for trauma and DPL are the most expedient and reliable methods of identifying significant intraperitoneal hemorrhage, although the FAST exam has largely replaced the use of DPL in most institutions. When readily available and used by trained individuals, FAST has the sensitivity, specificity, and accuracy of DPL in detecting hemoperitoneum, an injury that requires immediate surgical evaluation to determine the need for an operative intervention. In stable cases with a positive FAST result, abdominal CT scan may be appropriate to identify the source of bleeding and determine the need for any further intervention. Abdominal hemorrhage frequently comes from splenic or liver laceration, other visceral injury, or retroperitoneal hematoma. Patients with unstable or abnormal vital signs are usually not candidates for CT scanning and require surgery to control bleeding.

c. Pelvic Hemorrhage

Assessment of bony stability by means of physical examination and plain radiographs of the pelvis is crucial for early identification of major pelvic fractures. Patients with pelvic fractures (open-book or vertical shear) are at high risk for major bleeding, which is usually venous. Initial management includes vigorous blood volume replacement and, possibly, mechanical tamponade with a pelvic binder or bedsheet wrapped tightly around the pelvis to produce circumferential compression. External skeletal fixation may be helpful if the fracture anatomy is appropriate, and an orthopedic surgeon should be consulted early in the course of treatment. In patients with arterial bleeding associated with pelvic injury, CT scanning will reveal a blush of contrast. Pelvic angiography for embolization should be considered in the persistently hypotensive patient due to an increased likelihood for arterial bleeding. Angiography may be required in approximately 10% of patients with pelvic fractures. Recently, angiography has become the treatment of choice for control of bleeding from pelvic fractures and hematomas, even in the unstable patient.

d. Long Bone Fractures

Patients with long bone fractures will likely have associated hemorrhage in the surrounding injured tissue. Humerus and femur fractures may result in 1 to 3 units of blood loss, which can be problematic in the patient with multiple long bone fractures. Repeated physical examination for soft tissue swelling and changes in the diameter of the extremity will assist in the management of these patients.

e. External Hemorrhage

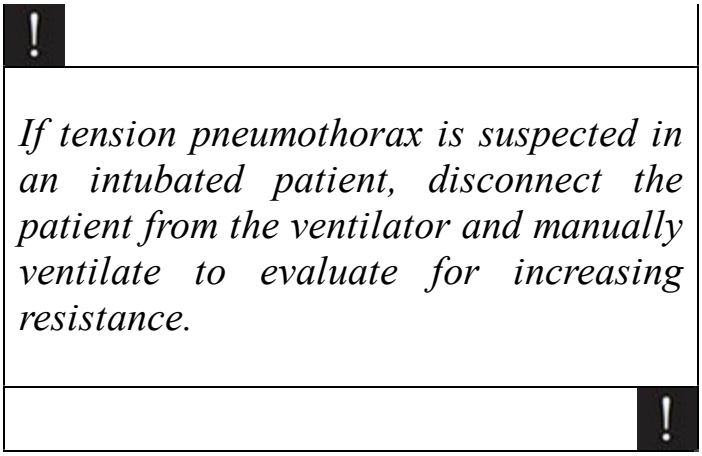
External hemorrhage can be very dramatic, as with a lacerated major arterial or venous blood vessel where direct pressure will decrease blood loss. Other cases, such as scalp lacerations, may go unrecognized as a possible source of significant blood loss. Rapid application of direct pressure, temporizing suture repair, or application of a tourniquet to a bleeding extremity may be lifesaving. One technique employs a blood pressure cuff inflated to a pressure higher than the patient's systolic blood pressure. Tourniquet use should be followed by surgical consultation as the tourniquet places the extremity in jeopardy of ischemic injury. In some situations, including military conflict and intentional mass casualty events, the early control of hemorrhage along with the liberal use of tourniquets can be lifesaving and may take priority in the initial evaluation and management.

6. Nonhemorrhagic Shock

The differential diagnosis of nonhemorrhagic shock in the trauma patient includes obstructive shock (tension pneumothorax, cardiac tamponade), blunt cardiac injury, air embolism, and neurogenic shock with acute spinal cord injury. Head injury is a rare cause of hypotension, but when it occurs, it is usually a preterminal event.

a. Tension Pneumothorax

Tension pneumothorax causes hemodynamic compromise and pulmonary dysfunction due to acute compression of the lung parenchyma and a shift of the mediastinum away from the hemithorax with the increased pressure. Do not wait for a chest radiograph to make this diagnosis. Breath sounds will be diminished, lung expansion will be asynchronous, and patients may develop respiratory distress, acute desaturation, bradycardia, and occasionally, distended neck veins. Classic venous distension may be absent in the setting of pneumothorax complicated by hypovolemia. All but gross changes in breath sounds may be difficult to detect in the resuscitation room. Tracheal shift is a late sign and may not be a presenting finding. In adults, needle chest decompression is performed via the midclavicular line in the second intercostal space; this is a lifesaving intervention that is followed by placement of a chest tube.



b. Cardiac Tamponade

The classic signs of cardiac tamponade — hypotension, distant heart sounds, jugular venous distension, and pulsus paradoxus — may be obscured due to noise and hypovolemia (decreasing jugular distention). Ultrasound (FAST) is a sensitive test for fluid in the pericardial sac. Pericardiocentesis via a surgical pericardial window should be considered for the patient with refractory shock, persistent central venous hypertension, and a high-risk penetrating wound (between the nipples, above the costal margin, below the clavicles). When surgical expertise is not available, a needle/catheter pericardiocentesis may be performed as a temporizing measure. Occasionally, major blunt chest trauma ruptures the cardiac surface. Most cases involve atrial tears and can be repaired if diagnosed early.

c. Blunt Cardiac Injury

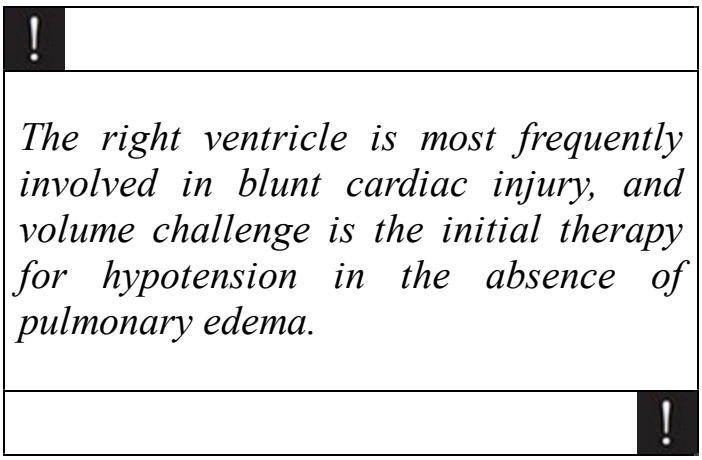
The diagnosis of blunt cardiac injury should be suspected in a patient involved in a high-speed, frontal impact accident who has unexplained hypotension or arrhythmia or, less commonly, cardiogenic shock. Changes in the electrocardiograms (ECGs) are usually nonspecific and can include premature ventricular contractions, bundle branch block, atrial fibrillation, unexplained sinus tachycardia, and ST-segment changes. If blunt cardiac injury is a possibility, a screening ECG should be obtained in the emergency department. Abnormalities other than tachycardia warrant 24 hours of monitoring for arrhythmias. Hemodynamically stable individuals with no ECG abnormalities need no further cardiac evaluation or observation. Echocardiography may be indicated in hypotensive patients to evaluate cardiac function. Use of cardiac troponins in diagnosing blunt cardiac injury is sometimes helpful. Treatment includes correction of acidosis, hypoxia, and electrolyte abnormalities; judicious administration of fluid; and pharmacologic treatment of life-threatening arrhythmias.

Inotropes may be indicated to support hemodynamic function. It is important to ensure that refractory hypotension is not due to ongoing blood loss. Patients may present with

acute myocardial infarction secondary to cardiac injury, or an acute myocardial infarction may have led to trauma (ie, fall, motor vehicle crash).

d. Neurogenic Shock

Neurogenic shock occurs when a cervical or high thoracic spinal cord injury (above T6 level) causes sympathectomy. It is characterized by hypotension, frequently associated with relative or absolute bradycardia. Flaccid paralysis, loss of extremity reflexes, and priapism may be associated neurologic findings. Treatment for hypotension includes volume resuscitation and vasopressors (phenylephrine or norepinephrine) if volume loading does not reverse the hypotension. Atropine or dopamine may be considered in the presence of bradycardia associated with hemodynamic instability.



B. Secondary Assessment: Diagnosis and Treatment of Other Injuries

Most patients with acute injuries can be resuscitated to a hemodynamically stable state. The primary survey should immediately identify acute life-threatening injuries. The next goal is to complete a secondary assessment to identify and treat other injuries. This assessment is crucial to allow proper triage to the operating room, radiology suite, or ICU.

1. History

Essential components of a patient's history include details of the mechanism of injury, previous medical illness, current medications, allergies, and tetanus immunization.

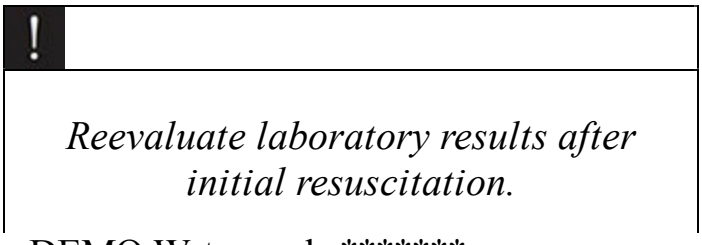
2. Physical Examination

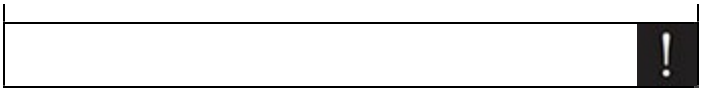
The patient should be examined from head to toe. The skull is carefully inspected to identify occult injuries. Signs of basilar skull fracture include hemotympanum,

rhinorrhea, or otorrhea; Battle sign (ecchymosis of the skin over the mastoid); and raccoon eyes. Facial bones, mandible, and neck are palpated for tenderness and crepitus. The GCS score and limited neurologic examination from the initial assessment are used to evaluate for head trauma (**Chapter 8**). Extraocular eye movements are checked to exclude muscle or nerve entrapment. The neck is inspected for distended neck veins, the position of the trachea, or subcutaneous emphysema. Neck pain or tenderness over the cervical spine warrants additional radiographs (see later section), CT, or magnetic resonance imaging. The chest is auscultated and palpated for tenderness and crepitus. The patient is log-rolled so that the thoracic and lumbar spine can be palpated for tenderness and other injuries can be detected. In penetrating trauma, exclude occult entrance or exit wounds in the axillary, cervical, or inguinal regions. The abdomen is likewise inspected, auscultated, and palpated. The pelvic bones are assessed for stability with lateral compression, anterior-posterior compression, and a gentle rocking motion; lack of pain with these motions in an awake patient without competing pain issues is usually sufficient to rule out significant pelvic bone fractures. The rectum is evaluated for tone and the presence or absence of blood and to ensure that the prostate gland is not displaced or difficult to palpate. The presence of perineal/scrotal hematoma and blood at the urethral meatus implies potential urogenital injury, which is a risk for urinary catheter insertion. The extremities are inspected, palpated, and evaluated for range of motion and neurovascular integrity.

3. Laboratory Studies

Minimal testing includes complete blood count, electrolyte measurements, blood glucose level, blood alcohol level, and toxicology screening. In any patient with evidence of hypovolemia, blood-group typing and a coagulation profile should be performed. Arterial blood gas measurements should be analyzed in selected patients to confirm adequate ventilation and perfusion (presence of acidosis). An elevated serum amylase level may be an indicator of pancreatic or bowel injury in the patient with blunt abdominal trauma. Creatinine phosphokinase should be checked if rhabdomyolysis is suspected. The hematocrit may not reflect the patient's acute volume status; without ongoing resuscitation equilibration by transcapillary fluid shifts can take hours to be reflected as a decrease in hematocrit. In general, a fall of 3% in the hematocrit is equivalent to 1 unit of blood loss. Serum lactate level measurements and follow-up to monitor clearance can help management and prognosis.





4. Radiologic Evaluation

a. General

In the evaluation of blunt multiple-system trauma, a supine chest radiograph and supine view of the pelvis are obtained as the primary survey is performed. This allows for interpretation of completed radiographs as the secondary survey begins. Plain films of the pelvis are crucial for early identification of major fractures and may allow for early placement of a pelvic binder to help reduce ongoing blood loss.

b. Head

CT scanning is essential for initial evaluation of a head-injured patient or in any patient with a decreased or altered level of consciousness. Many centers will also obtain a CT scan of the cervical spine when the head scan is obtained.

c. Spine

The initial lateral C-spine radiograph has been largely abandoned for the diagnosis of cervical spine injury. Given the common issues in obtaining adequate cervical spine images, including inadequate visualization of the spine between C7 and T1 and poor definition of the occiput, most centers now obtain a CT evaluation of any areas that cannot be clinically cleared or have concerning results on physical exam. In the patient with increased risk of C-spine injury, cervical immobilization is crucial until these studies are reviewed and correlated with a reliable physical examination for evidence of tenderness. However, patients should be removed from a rigid spine board expeditiously due to the risk of skin pressure injury with extended immobilization. Magnetic resonance imaging is helpful for disc, spinal cord, and ligament injuries. If a C-spine fracture is found, radiographic screening of the entire spine is indicated because ~10% of these patients will have a second, noncontiguous vertebral column fracture. CT scans of chest and abdomen often can be reformatted to provide information on spine injury without the need for additional plain radiographs or additional radiation exposure.

Neurologic examination alone does not exclude a C-spine injury. The following considerations apply to patients at risk for C-spine injury:

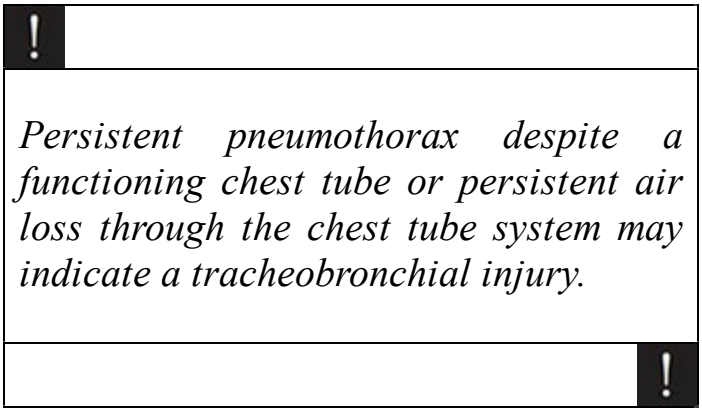
- Patients who are alert, awake, and have no changes in neurologic status or neck pain may be considered to have a stable C-spine and need no radiologic studies.

Beware of injuries that could distract the patient with C-spine injury.

- Early CT scans may facilitate evaluation of the C-spine in any head-injured or intubated patient. Adding CT evaluation of the C-spine to the initial CT scan of the head is an appropriate strategy after injury.
- The presence of paraplegia or quadriplegia is presumptive evidence of spinal instability.
- Patients with neurologic deficits potentially due to a C-spine injury require spine surgery consultation.
- Exclusion of any bony injury does not eliminate the possibility of ligamentous disruption. Magnetic resonance imaging can facilitate clearance of ligamentous injury if the examination is not reliable.

d. Chest

Once the spine is cleared for fractures, an upright (or reverse Trendelenburg) chest radiograph is indicated to better define or identify pneumothorax, hemothorax, mediastinal widening or irregularity (concern for aortic transection), or fractures, as well as to confirm the position of various tubes. Chest radiographs are inadequate to rule out aortic injury when a significant lateral impact or deceleration injury exists. Suspect this lethal injury where the mediastinum is widened on chest radiographs and an appropriate mechanism is involved. CT angiography provides an excellent method to screen for aortic injury and define other thoracic injuries. Its use has largely replaced traditional angiography in the initial diagnosis of thoracic aortic injuries.



e. Abdomen

Plain abdominal radiographs are not usually helpful. In the hemodynamically stable patient, a CT scan of the abdomen and pelvis and the FAST examination are the mainstays of abdominal evaluation in a trauma patient. FAST can be followed up with a

CT scan of the abdomen if free peritoneal fluid is identified in the stable patient. DPL may still be used in certain circumstances, but has generally been replaced by the CT imaging and the FAST exam.

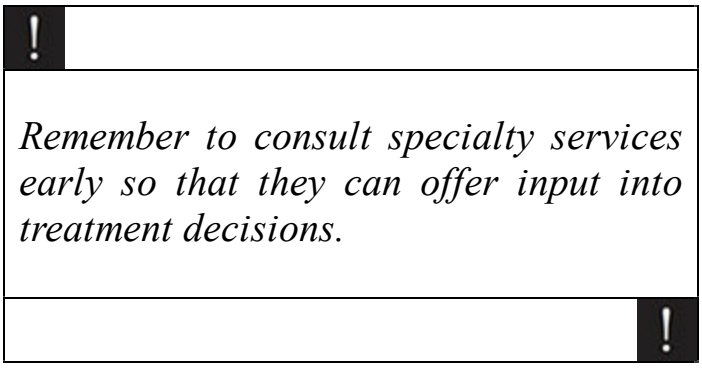
f. Genitourinary Tract

Hematuria may be evaluated with a CT scan or other contrast studies. It provides anatomic detail about abdominal and retroperitoneal structures and any direct injury to the kidney(s). If physical examination suggests that a urethral injury is present, a urethrogram should be obtained before urinary catheterization. A cystogram may be indicated if bladder injury is suspected. Intravenous pyelograms are not commonly performed.

g. Skeletal Fractures

Films of the extremities (anterior posterior and lateral views) should be obtained on the basis of physical examination or patient complaint. Films should include the joint above and below the site of injury.

5. Other Issues



A nasogastric tube serves to decompress the stomach and may reduce the risk of pulmonary aspiration; however, it should be placed orally in patients with midfacial fractures or possible basilar skull fractures. Blood in the gastric aspirate may be the only sign of an otherwise occult injury to the stomach or duodenum, and further investigation may be indicated. Tetanus prophylaxis is routine (**Table 9-3**). Systemic antibiotics should usually be withheld until a specific indication is determined, but they are employed in three situations: (1) patients undergoing intracranial pressure monitoring or chest tube placement frequently receive gram-positive coverage when the device is inserted; (2) patients with penetrating abdominal trauma may be given coverage for gram-negative aerobic and anaerobic organisms for the first 24 hours after injury; and (3) patients with open fractures are given gram-positive coverage for 24

hours as orthopedic evaluation is arranged.

Table 9-3	Guide to Tetanus Prophylaxis in Routine Wound Management[a]			
History of Absorbed Tetanus Toxoid	**Clean Minor Wounds (Not prone to tetanus[b])**		**All Other Wounds[b] (Tetanus-prone[c])**	
	Tdap or Td[b]	**TIG[d]**	**Tdap or Td[b]**	**TIG[d]**
Unknown or <3 doses	Yes	No	Yes	Yes
≥3 doses[e]	No[f]	No	No[g]	No

Abbreviations: Tdap, tetanus toxoid, reduced diphtheria toxoid, acellular pertussis vaccine; Td, tetanus toxoid and reduced diphtheria toxoid — for adult use (dose = 0.5 mL); TIG, tetanus immune globulin — human (dose = 250 IU).

[a]Patients who have completed a three-dose primary tetanus vaccination series and have received a tetanus toxoid-containing vaccine <5 years before the injury do not require a tetanus toxoid-containing vaccine for wound management.
[b]Children <7 years = Tdap is recommended; if pertussis vaccine is contraindicated, Td is given. Children 7-9 years or adults >65 years = Td is recommended. Children and adults 10-64 years = Tdap is preferred to Td if the patient has never received Tdap and has no contraindication to pertussis vaccine. For patients >7 years of age, if Tdap is not available or not indicated because of age, Td is preferred to tetanus toxoid.
[c]Such as (but not limited to) wounds contaminated with dirt, feces, soil, and saliva; puncture wounds; avulsions; and wounds resulting from missiles, crushing, burns, and frostbite.
[d]Equine tetanus antitoxin should be used when TIG is not available.
[e]If only three doses of fluid toxoid have been received, a fourth dose – preferably an adsorbed toxoid – should be given. Although licensed, fluid tetanus toxoid is rarely used.
[f]Yes, if ≥10 years since the last tetanus toxoid-containing dose.
[g]Yes, if ≥5 years since the last tetanus toxoid-containing dose; more frequent boosters are not needed and can accentuate side effects.

Female patients of childbearing age should be questioned about the possibility of pregnancy or be checked with a β-human chorionic gonadotropin test before extensive radiographic evaluation is performed unless significant hemodynamic instability is present. The priority with the unstable pregnant patient always has to be maternal resuscitation and stabilization. Anyone in her second or third trimester should be positioned with a wedge under her back to elevate the right side, avoiding compression of the vena cava. This is done only after examination of the spine and pelvis does not reveal any pain or tenderness, which may indicate a fracture. Remember that the optimal care of the mother yields optimal care for the fetus. Obstetrical consultation should be considered (**Chapter 14**).

Another important issue is the need for adequate tetanus prophylaxis in patients with open wounds. The patient's current vaccination status must be verified and updated if needed. In those who have an unclear immunization status or with especially contaminated tetanus-prone wounds, the use of tetanus immune globulin should be considered (**Table 9-3**).

Case Study

A middle-aged man sustained multiple liver lacerations in a motor vehicle crash. He also had mesenteric lacerations and bowel resection was performed. The ends of the bowel were stapled, and the abdomen was filled with packs to control venous bleeding from the liver. He continues to require fluid resuscitation and administration of blood products due to coagulopathy. Several hours after admission to the ICU, increased airway pressures and falling urine output are noted.

– What are possible causes of increased airway pressures?

– Why has the urine output fallen?

After life- and limb-threatening injuries have been addressed and metabolic derangements have been corrected, periodic systematic assessment is performed to identify occult injuries not evident at presentation.

1. Head Injury

Evaluation of the head-injured patient is an ongoing process requiring early neurosurgical consultation. Serial assessment of the GCS scores, pupil size and response, and presence or absence of lateralizing neurologic signs is crucial. Any changes in examination results are noted and acted upon as they are discovered.

Serial CT scans of the head may offer clinically useful information, but the key to patient management is detection of changes in physical examination. Continued resuscitation is imperative to avoid secondary brain injury, which typically occurs when a patient becomes hypoxic or hypotensive during acute care. These secondary insults increase the likelihood of poor outcome (**Chapter 8**).

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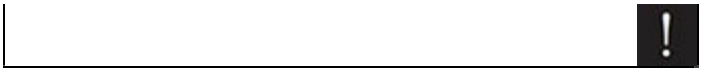
The administration of atropine or dopamine, as well as mydriatic agents, may dilate the pupils and lead to a false diagnosis of a more severe head injury.



2. Pulmonary Injury

Trauma patients often have a full stomach at the time of injury and experience aspiration. Aspiration of the acidic gastric contents may cause a chemical pneumonitis initially and predispose patients to an infective pneumonitis or acute respiratory distress syndrome later. Antibiotics are not indicated in initial management. Bronchoscopy may be needed for removal of large particulate matter.

Delayed onset of pneumothorax or hemothorax may follow chest trauma. Additionally, pulmonary contusions and resulting acute respiratory distress syndrome may not become obvious until later (12-48 hours). Continued assessment includes physical examination, oximetry and/or arterial blood gas measurements, chest radiographs, and ventilatory mechanics.

3. Cardiac Injury

Continuous ECG monitoring and frequent measurements of blood pressure are mandatory in the emergency department and ICU. Continuous arterial blood pressure monitoring may be indicated (**Chapter 6**). Electrolyte disturbances may lead to cardiac contractile dysfunction or arrhythmias in the aggressively resuscitated trauma patient. Common electrolyte disturbances include hyperchloremia, hypokalemia and hyperkalemia, hypomagnesemia, and hypocalcemia.

4. Abdominal Injury

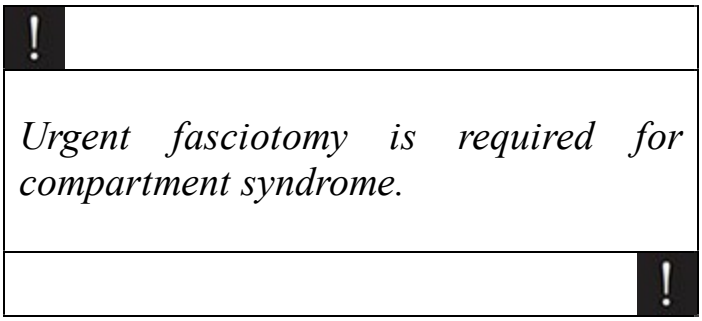
Substance abuse or neurologic injury may not allow reliable initial abdominal examination. Perforation of a hollow viscus in blunt trauma is sometimes difficult to diagnose. Free air under the diaphragm on an upright chest radiograph, over the liver on a left lateral decubitus radiograph, or on an abdominal CT indicates the need for operative exploration. CT scanning also provides information about the retroperitoneum. In the head-injured patient who is undergoing a head CT scan and has a nonoperative neurologic injury, abdominal scanning should be considered, as physical examination may be unreliable. However, caution must be used in the clinical interpretation of CT imaging for hollow viscus injury - a negative scan does not absolutely rule out the possibility of an occult injury.

A frequently missed condition is abdominal compartment syndrome. This condition occurs when intra-abdominal pressure increases due to intraperitoneal or retroperitoneal hemorrhage, ascitic fluid accumulation, edema secondary to massive

fluid resuscitation, or intraoperative surgical closure of the abdomen under tension. Increased intra-abdominal pressure decreases cardiac output and compresses the vascular bed and kidneys. The diaphragm is displaced upward by increased intra-abdominal pressure, which results in decreased thoracic volume and compliance. Decreased volume within the pleural cavity predisposes to atelectasis, and ventilated patients with intra-abdominal hypertension require increased airway pressure to deliver a fixed tidal volume. Vascular compression can decrease blood flow to the liver and kidneys with resultant dysfunction. Finally, intra-abdominal hypertension significantly increases intracranial pressure (**Chapter 13**).

5. Musculoskeletal Injury

The neurologic and vascular evaluation of the extremities is an ongoing process. A swollen and tense extremity should be watched closely for the development of a compartment syndrome, particularly in patients with decreased responsiveness. In alert patients, serial physical examination is the best monitoring method. Classical signs include pain, pallor, pulselessness, paresthesia, and/or paralysis. Loss of pulse is a very late finding. The most helpful early signs are complaints of pain out of proportion to physical findings and severe pain on passive stretch of the involved muscle groups. In the unconscious patient or when the examination is unreliable, compartment pressure may be monitored using a needle with a standard gauge. Pressures >30 mm Hg warrant consideration of fasciotomy.



Musculoskeletal examination should be repeated, either as patients recover from other injuries or as their mental status clears, to identify new pain or tenderness. Plain radiographs should then be obtained to identify occult fractures. Commonly missed orthopedic injuries include fractures of the scapula, thoracic and lumbar spine, pelvis, ankle, and wrist.

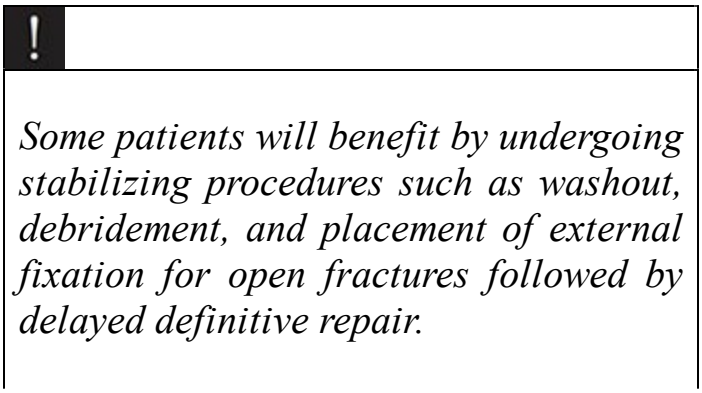
Crush syndrome should be considered when patients have been trapped, injury to large muscle mass is involved, prolonged compression has occurred with protracted immobilization, or vascular compromise is present (such as tourniquet use or compartment syndrome). Crush syndrome develops when damaged myocytes lyse,

releasing myoglobin, potassium, phosphorus, and calcium. Manifestations of this syndrome include cardiac dysrhythmias, renal failure, metabolic acidosis, and hypovolemia. Preemptive hydration before reperfusion of crushed muscle mass usually is accomplished before arrival at the hospital. Revascularization of ischemic extremities, fasciotomy for compartment syndrome, or release of tourniquets can mimic this situation. Before reperfusion, normal saline should be administered (1- to 2-L bolus or 10-15 mL/kg/h). Careful monitoring for cardiac signs of hyperkalemia should be instituted. After reperfusion, aggressive hydration to maintain urine output above 3 to 4 mL/kg/h helps prevent heme pigment-associated renal injury. Adjuvants such as bicarbonate and mannitol may be used.

6. Other Considerations

Resuscitation is an ongoing process. Traditional end points such as normalization of blood pressure, heart rate, and urine output may not always reflect complete correction of the shock state. The attainment of normal vital signs can occur even in the setting of tissue hypoperfusion resulting in a compensated state of shock. Lactate concentration and resolution of metabolic acidosis may provide more definitive end points for adequacy of resuscitation. Because the time to normalization of these parameters is predictive of survival, additional resuscitation in the form of volume replacement, red cell transfusion, or support with vasoactive agents may be indicated within the first 24 hours following injury despite normal or near-normal vital signs. Persistence of a metabolic acidosis or elevated lactate concentration may be an early indicator of complications, including ongoing hemorrhage or abdominal compartment syndrome.

Damage control surgery (initially limited to control of bleeding and decontamination of hollow organ ruptures with spillage) may be needed in the first 24 to 48 hours, before definitive surgery is performed. Many trauma patients benefit from delayed definitive surgery, particularly the repair of fractures, during this period of ongoing stabilization. Decisions to proceed with surgery should be made after appropriate consultation with the primary surgical service, a critical care physician, and other consultants as indicated.



In the immediate resuscitation period, periodic reassessments are important. Once a patient is stabilized, all intravenous access sites should be reassessed. Because full sterile precautions to prevent line-related infections may not be feasible during emergency vascular access, many lines will need to be replaced. If central venous access is no longer indicated, it should be discontinued.

III. BURN INJURY: INITIAL EVALUATION AND STABILIZATION

Case Study

A young man is brought in after a gasoline can exploded as he was burning brush. The patient sustained a full-thickness burn injury to both forearms and showed signs of flash-burn injury to his face. He is in no respiratory distress and has received no fluids since his injury. Although he has no abdominal burns, he complains of abdominal pain. Family members recall that the patient was thrown into a tree stump by the explosion. You are asked to see the patient in the emergency department to assist during his initial wound care.

– What are the initial evaluation priorities?

– What is the greatest risk to this patient?

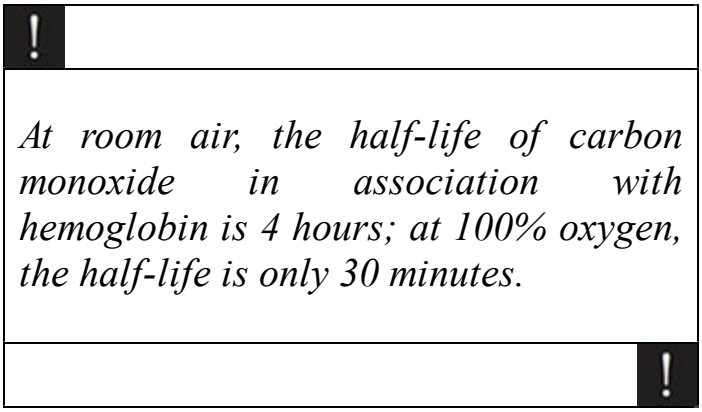
A. General

Burn injuries represent a significant cause of morbidity and mortality. Deaths from burn injury occur with greatest frequency as a result of residential fires with smoke inhalation. Like other forms of injury, burns tend to be frequent in the young and the elderly. Scalds are the most common form of childhood injury, whereas electrical and chemical injuries affect adults in the workplace. Factors that affect burn mortality include size of cutaneous injury, patient age, and presence or absence of inhalation injury. Burn injuries should not distract providers from seeking other potential traumatic injuries. The initial evaluation and treatment of a serious burn injury follows the same pathway as trauma, including the primary and secondary surveys.

B. Airway/Breathing

The initial evaluation of the airway is directed, in part, by the history of the injury. Patients who are at the greatest risk of smoke inhalation injury typically have a history of being in a closed space with flame and smoke. With increased exposure time, the likelihood of injury increases. Smoke inhalation injury can be described by three mechanisms. These include particulate injury, toxic byproducts of combustion injury, and direct thermal injury. Particulates found in the soot and smoke of the fire are responsible for a reactive airway injury that may result in bronchospasm. Toxic exposure may have direct cytotoxic effect on alveolar tissue or affect energy-generating pathways, or bind hemoglobin and reduce the availability of oxygen for intracellular use. Direct thermal injury can result in oral, nasal, and upper respiratory injury with airway swelling.

Inhalation injury is generally diagnosed by a combination of clinical signs and symptoms confirmed by bronchoscopy. Clinical findings include facial burns, parched oral mucosa, nasal singeing, soot in the oral and nasal passages, and symptoms of reactive airway exacerbation. Bronchoscopic findings include mucosal edema, ulceration, sloughing, and mucous plugging. Chest radiographs are frequently normal at admission, and hypoxemia often is not appreciated.



At room air, the half-life of carbon monoxide in association with hemoglobin is 4 hours; at 100% oxygen, the half-life is only 30 minutes.

Three stages of inhalation injury have been identified:

1. Acute hypoxia with asphyxia typically occurs at the scene of the fire.
2. Upper airway and pulmonary edema may evolve during the first hours to days after injury.
3. Infectious complications that stem from exposure to heat and chemical irritants may appear later (eg, pneumonia).

Treatment of inhalation injury is largely supportive. If exposure to carbon monoxide is

suspected, 100% oxygen should be provided. Early intubation is advocated, especially if the patient will be transferred, because pulmonary and laryngeal injury may quickly evolve even though the initial airway assessment is satisfactory. Caution should be exercised in the use of succinylcholine due to the possibility of clinically significant hyperkalemia. Intravascular resuscitation should not be delayed or withheld because inhalation injury increases resuscitation fluid requirements. Humidification of inhaled gases helps in secretion control and reduces desiccation injury to the airway.

C. Circulation

Patients sustaining small burns (<20% total body surface area [TBSA]) typically will have normal vital signs. Those with larger burns (>20% TBSA) may develop burn shock. This is due to a diffuse capillary leak syndrome resulting from the release of cytokines, interleukins, and vasoactive amines and causing third spacing of fluid. The combined loss of fluid from the burned surface area and the interstitial edema may result in the loss of circulating volume. Systemic hypotension may ensue. Resuscitation following the American Burn Association recommendations (discussed later) should be followed as it permits large volumes of fluid to be administered over an extended period. Large-bore peripheral intravenous catheters should be placed (through the burn, if necessary). The preferred resuscitation fluid is lactated Ringer solution.

D. Assessment of Injury

The approach to the initial assessment is the same as in trauma. An initial primary survey (ABCDE) is performed, followed by a head-to-toe examination. All clothes must be removed to determine burn size, and the patient must be covered with blankets because heat is lost quickly. Depending upon the history, the patient may have other injuries and should be assessed for trauma in accordance with the guidelines outlined.

1. Depth of Burns

There are three burn depths:

1. First-degree (superficial): erythematous, painful
2. Second-degree (partial thickness): red, swollen, blistered, weeping, very painful
3. Third-degree (full thickness): white, leathery, painless

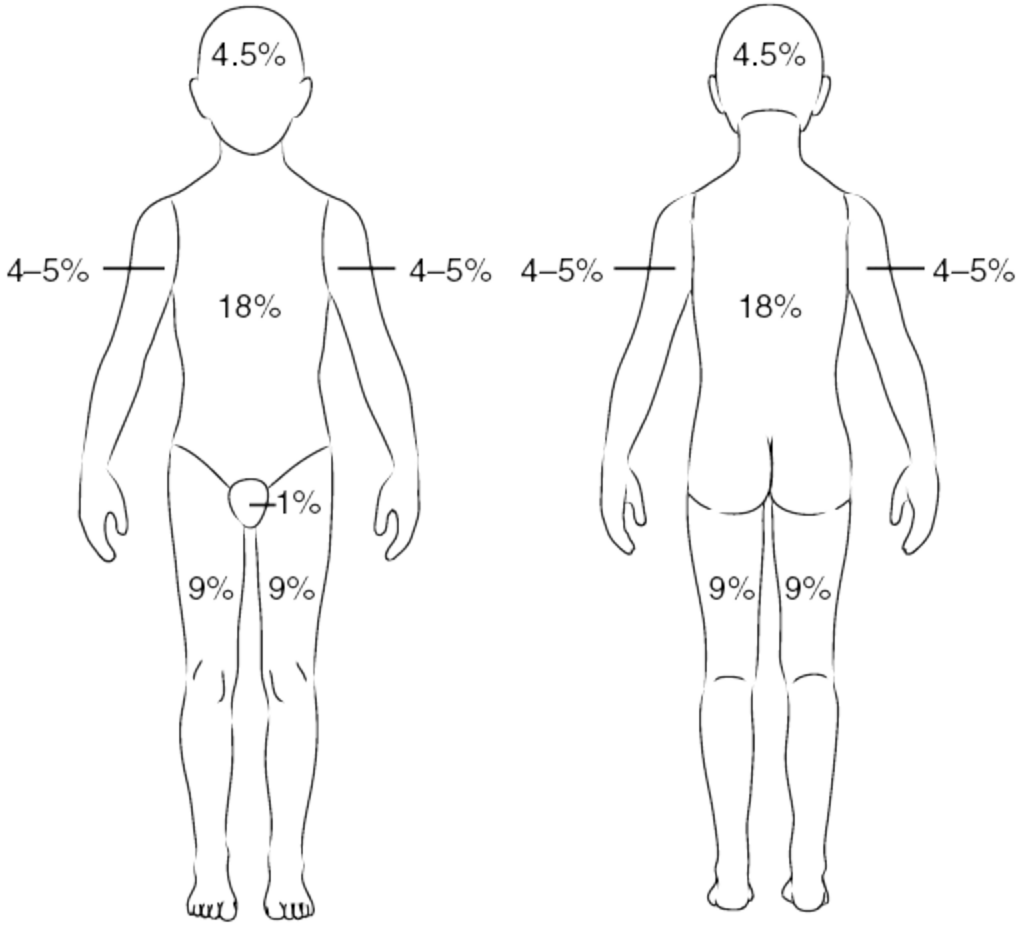
Third-degree or full-thickness injuries involve all layers of the epidermis and dermis

and require surgical reconstruction. Burns that involve deep structures, such as tendon, muscle, and bone, have been called fourth-degree burns.

2. Burn Area (Rule of Nines)

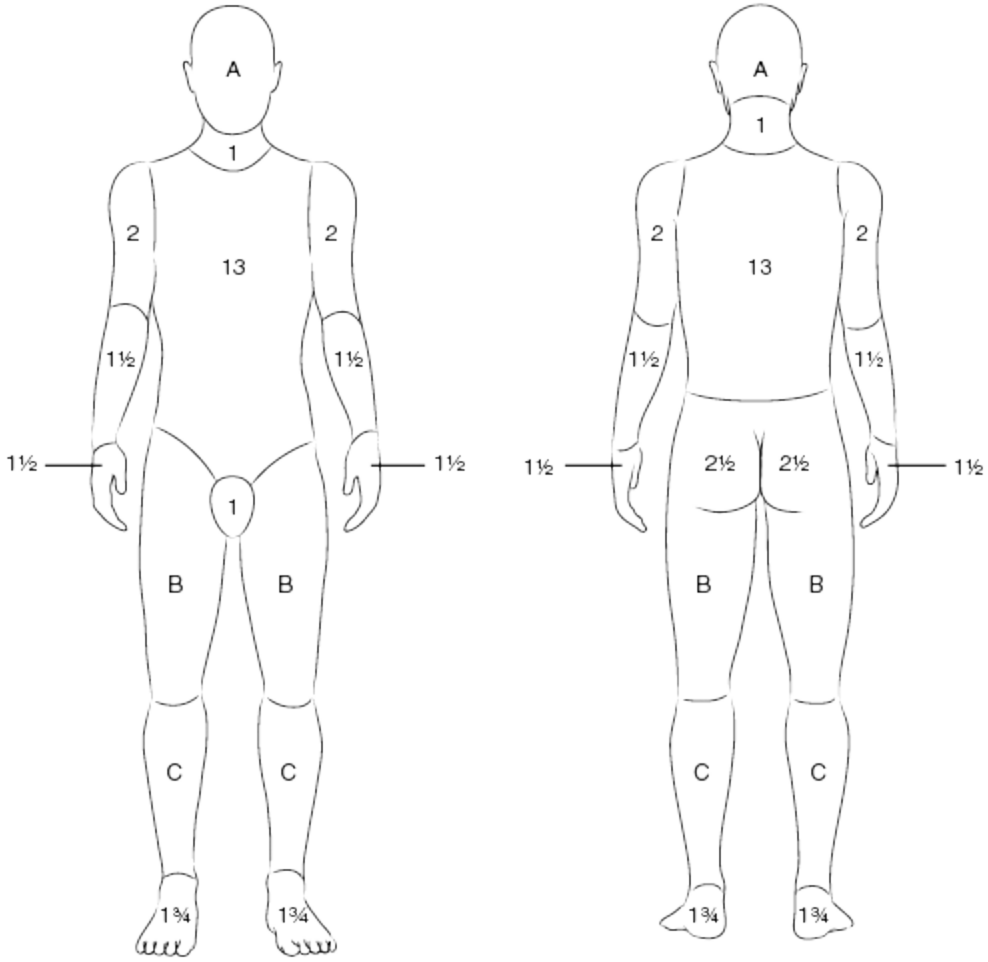
The rule of nines is commonly used to estimate the surface area that has been burned (**Figure 9-1**). The head and upper extremities each represent 9% of the TBSA. The anterior and posterior trunk and the lower extremities each represent 18%, and the perineum represents 1% of the TBSA. In children, the head is proportionally larger, leading to a relative decrease in the area of other body segments. Alternatively, the patient's hand, which equals roughly 1% of TBSA, may be used to estimate the size of a small or irregular burn. An often used tool to estimate the total body surface area in children younger than 15 years is the Lund-Browder Chart (**Figure 9-2**).

Figure 9-1. Rule of Nines



Most appropriate for adults and children over 15 years of age.

Figure 9-2. Lund-Browder Chart



LUND-BROWDER CHART
Relative Percentage of Body Surface Area Affected by Growth

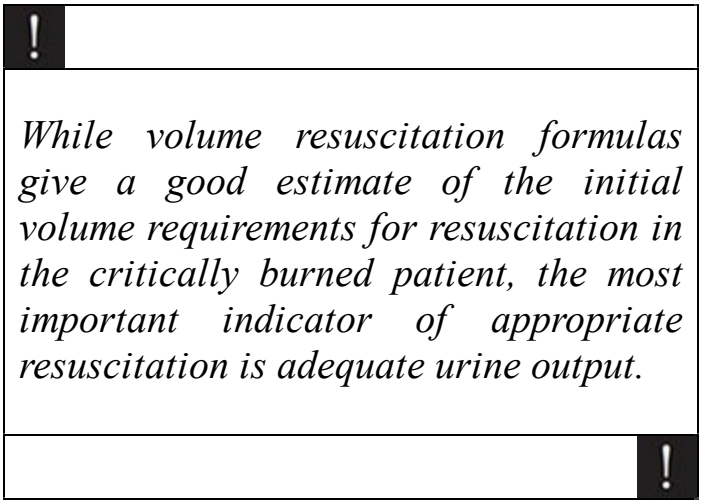
Age in years	0	1	5	10	15	Adult
A-head (back or front)	9½	8½	6½	5½	4½	3½
B-1 thigh (back or front)	2¾	3¼	4	4¼	4½	4¾
C-1 leg (back or front)	2½	2½	2¾	3	3¼	3½

The Lund-Browder chart is the most accurate method for estimating burn extent and must be used in the evaluation of pediatric patients under 15 years of age.

E. Resuscitation

Burn shock presents with profound hypovolemia, which has both interstitial and intracellular components. Increased capillary permeability is one of the key components of the burn shock response. In small burns, maximal edema is seen 8 to 12 hours after injury; larger burns at 12 to 24 hours. Plasma volume loss coincides with edema formation and increased extracellular fluid. Edema is affected by fluid administration

during resuscitation. Fluid and electrolytes should be replaced as dictated by organ perfusion indicators and electrolyte imbalance. Because fluid and electrolyte losses in burns are primarily insensible, fluid lost cannot be quantified adequately. Venous access should be obtained and a urinary catheter placed. The American Burn Association recommends the consensus formula of 2 to 4 mL/kg/% TBSA as an estimation of the fluid requirements in the initial 24 hours after serious burn injuries. Beginning at the low end of this range may reduce edema and extravascular complications such as abdominal compartment syndrome. The TBSA is calculated only for second- or third-degree burns. Resuscitation is carried out with Ringer lactate solution. Half of the crystalloid resuscitation should be administered in the first 8 hours, the remaining over the next 16 hours. Surrogate markers of adequate resuscitation include normalization of blood pressure, heart rate, and urine output. Appropriate urine output in adults is 0.5 to 1 mL/kg/h and 1 to 1.5 mL/kg/h in children. An arterial blood gas measurement to monitor the pH and base deficit and serum lactate levels are also good markers of adequate resuscitation. While appropriate resuscitation is critical to maintain physiology, care must be taken to avoid over-resuscitation as this can lead to significant increases in edema and result in progression of the burn injury.



A circumferential burn to an extremity may develop significant edema that the underlying tissue cannot accommodate due to the constrictive nature of the burn wound. Impaired limb and tissue perfusion may ensue that can only be managed by performing an escharotomy to the extremity and/or digits. In larger burns of the abdomen and chest wall, a compartment syndrome may develop whereby cardiovascular and respiratory compromise may mandate torso escharotomies or abdominal decompression. Surgical consultation should be sought immediately for any of these problems.

F. Carbon Monoxide Exposure

A fire in an enclosed space mandates consideration of carbon monoxide poisoning in addition to the worry for inhalation injury. The typical oxygen saturation monitor will not detect carbon monoxide and can give artificially elevated oxygen saturation levels; therefore, if carbon monoxide poisoning is suspected, an arterial blood gas with a carboxyhemoglobin level will clarify the clinical picture. High-flow 100% oxygen will reduce the half-life of carbon monoxide in the plasma and is the primary treatment. Early use of hyperbaric oxygen for patients with high carboxyhemoglobin levels (>25%) or evidence of significant neurologic or cardiovascular toxicity has been recommended, but data supporting this recommendation are limited.

G. Burn Wound

Local wound care begins with serial debridement of nonviable tissue and blisters by appropriate surgical consultants. Little care is required for the burn wound before transfer to the burn center or surgical consultation. If gross contamination is present, a gentle washing and coverage with clean linen may be appropriate. If the patient cannot be rapidly transferred to a burn center, it may be necessary to apply silver sulfadiazine (or appropriate antibiotic ointment) and occlusive dressings to help prevent evaporative heat loss.

H. Other Considerations

Placement of a nasogastric tube is indicated if the patient vomits, requires intubation, or has a burn >20% of TBSA. This may also prove beneficial to provide nutritional support for large burns, given the high nutritional requirements. Intravenous opiates should be given for pain. Rings and bracelets should be removed as they may cause constriction early in resuscitation. Burns are tetanus-prone injuries, and tetanus prophylaxis should be reviewed (**Table 9-3**).

I. Special Considerations

1. Chemical Burns

Chemical burns may be caused by acid (eg, cleaning products, industrial applications), alkali (eg, hydrides of sodium, potassium, and sodas of ammonia), or organic compounds (eg, petroleum products). Severity of injury relates to the agent involved, its concentration, and the duration of contact. Initial care requires removing the patient from the source of chemical injury immediately. In general, removal of clothing is

essential. Dry substances should be brushed off and the area irrigated copiously with water. Do not use neutralizing agents as they may increase the severity of burn.

Contact with petroleum products (such as spilled gasoline at the scene of a motor vehicle crash) is associated with rapid skin penetration and late multiple-organ failure. Again, rapid removal of the patient from the source and vigorous irrigation of exposed surfaces are warranted. Advice regarding chemical burns is available from regional burn centers.

2. Electrical Injury

Electrical injury is a syndrome with a variety of presentations. Exposure to an electrical source <1,000 volts produces a low voltage injury similar to other cutaneous burns. When exposure exceeds 1,000 volts, a greater potential for deep as well as cutaneous injury exists.

Three types of skin injury can occur with electrocution:

1. Entrance and exit wounds, typically circumscribed, deep lesions, occur at points of contact with the electrical source or ground (usually hands and feet).
2. Cutaneous burns may be caused by arc injury from the primary site to the patient, a flash injury, or an actual flame injury if clothing catches fire.
3. Deep soft tissue injuries involve muscle, nerve, or the vascular bed as current passes through the tissue.

Beware of pneumothorax, airway compromise, cardiac arrest, and blunt injury secondary to falls and violent muscle contraction. Muscle compartment pressures may increase, necessitating fasciotomy, not just escharotomy. If myoglobin is present in the urine or creatine kinase concentrations are elevated, provide adequate intravascular fluid to increase the urine output to 3 to 4 mL/kg/h until resolution of the rhabdomyolysis. Patients may develop ileus after electrocution. The ECG should be reviewed in electrical injury.

The initial priority in the management of electrocution is removal of necrotic tissue and decompression of compromised deep tissue compartments, particularly muscle. Resuscitation is begun at 4 mL/kg/% TBSA cutaneous injury and titrated to maintain urine output of 0.5 to 1 mL/kg/h unless rhabdomyolysis is present and higher urine output is desirable. Aggressive fluid resuscitation potentiates filtering of pigment and dilution of iron (nephrotoxic). Alkalinization of the urine may be considered to decrease the nephrotoxic potential despite lack of supportive evidence. If large areas of soft-

tissue injury are present, surgical consultation should be requested. As with other burns, infection is the chief risk, but other potential problems are myocardial and vascular injury, encephalopathy, cataracts, and gut perforation.

Lightning injury may be thought of as massive exposure to direct current. Most injury is topical because exposure times are extremely brief. Mortality rates associated with lightning relate to early cardiac and respiratory arrest. Aggressive basic and advanced life support may be lifesaving for these patients.

IV. REFERRAL AND TRANSFER CONSIDERATIONS

Early involvement of surgical expertise is important in the care of the injured patient. A surgeon should be summoned as soon as it is known that a seriously injured patient is arriving. Early neurosurgical consultation is advised for patients with head injury.

General guidelines for field triage and interfacility transfer have used physiologic, anatomic, and high-risk mechanistic criteria to suggest triggers for triage and transfer. One may extrapolate that these parameters can be used to initiate involvement of a trauma surgeon as well. Some triggers are suggested in **Table 9-4** and **Table 9-5**.

Table 9-4	American Burn Association Criteria for Patient Transfer to a Burn Center[a]

- Partial-thickness burns greater than 10% of total body surface area
- Third-degree burns in any age group
- Burns involving the face, hands, feet, genitalia, perineum, or major joints
- Patients at the extremes of age or those with significant comorbid disease
- Electric burns and chemical burns
- Smoke inhalation injury
- Patients with combined trauma and significant burn injury
- Children at hospitals with no expertise in caring for pediatric burn patients
- Burns suspected to be due to child or elder abuse
- Burn patients with a delayed presentation or evidence of burn wound infection

[a]Adapted with permission from the American College of Surgeons. American College of Surgeons Committee on Trauma. Guidelines for the operation of burn centers. In: *Resources for Optimal Care of the Injured Patient*. Chicago, IL: American College of Surgeons; 2006:79-86.

Table 9-5	Indications for Field Triage and Interfacility Transfer[a]

Physiologic Criteria

- Glasgow Coma Scale score of <13
- Systolic blood pressure <90 mm Hg
- Respiratory rate <10 breaths/min or >29 breaths/min (<20 breaths/min in infant <1 year)

Anatomic/Injury Triggers

- Penetrating injuries to head, neck, torso, and extremities proximal elbow or knee
- Chest wall instability or deformity
- Amputation proximal to the wrist or ankle
- Two or more proximal long bone fractures
- Crushed, degloved, mangled, or pulseless extremity
- Pelvic fracture
- Open or depressed skull fracture
- Paralysis

Mechanism of Injury Triggers

- Adult: falls >20 feet
- Children: falls >10 feet
- High-risk automobile crash
    - Intrusion: >12 inches occupant side; >18 inches any side (including roof)
    - Ejection (partial or complete) from automobile
    - Death in same passenger compartment
    - Vehicle telemetry data consistent with high risk of injury
- Auto vs. pedestrian/bicyclist: thrown, run over, or with significant (>20 mph) impact
- Motorcycle crash >20 mph

Patient Triggers

- Age >55 years
- Systolic blood pressure <110 mm Hg in persons aged >65 years
- Falls in older adults (including ground level falls)
- Pediatric trauma transport
- Anticoagulant use or bleeding disorders
- Burns
- Pregnancy >20 weeks
- Judgment of emergency medical services provider

[a]Adapted from Centers for Disease Control and Prevention. Guidelines for field triage of injured patients: Recommendations of the National Expert Panel on Field Triage, 2011. *MMWR Recomm Rep*. 2012;61(1):1-21.

If appropriate surgical services are unavailable, early transfer to the closest trauma or burn center should be initiated. This should not be delayed for additional radiologic studies if surgical resources are unavailable, unless those studies are requested by the accepting physician. The trauma center should be contacted for advice and to discuss potential problems or concerns with transport personnel.

Common pitfalls in the transfer of seriously ill patients include failure to intubate before

transfer, failure to recognize the need for transfer to a higher level of care, and a general failure to stabilize the patient adequately before transport. Unrecognized ongoing hemorrhage, delayed onset of tension pneumothorax, and reversible/preventable causes of secondary brain injury must be considered.

Key Points

Basic Trauma and Burn Support

- The first goal in trauma management is to identify and treat immediately life-threatening injuries by following the ABCDE sequence of priorities.
- After blunt trauma, airway control should proceed on the assumption that an unstable cervical spine injury exists.
- A diagnosis of tension pneumothorax should be based on clinical criteria and not on a chest radiograph.
- Hemorrhage is the most likely cause of shock after injury, and initial empiric treatment consists of crystalloid infusion to normalize blood pressure, reverse tachycardia, and maintain adequate organ perfusion.
- In general, blood should be added to resuscitation early if the response is inadequate or if continued ongoing hemorrhage is suspected. Uncrossmatched, type-specific blood can be administered safely.
- A secondary assessment includes a head-to-toe examination to identify and treat potentially life-threatening injuries.
- Computed tomographic scanning is essential for the initial evaluation of head-injured patients with a depressed level of consciousness.
- Burn resuscitation is proportional to the area sustaining second- and third-degree burns and is titrated to signs of perfusion. Adequate urine output is one of the key indicators of adequate resuscitation.
- Closed-space smoke inhalation injury places the patient at high risk for upper airway and inhalation injury that may not be obvious at the initial presentation.
- Surgical expertise should be secured early and transfer considered for those

patients who require a higher level of care.

- Transfer to a specialized care setting should not be delayed for additional radiologic studies unless the accepting physician requests the studies.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. American College of Surgeons Committee on Trauma. *Advanced Trauma Life Support for Doctors (ATLS): Student Course Manual*. 9th ed. Chicago, IL: American College of Surgeons; 2012.
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16. Sarrafzadeh AS, Peltonen EE, Kaisers U, et al. Secondary insults in severe head injury: Do multiply injured patients do worse? *Crit Care Med*. 2001;29:1116-1123.

17. Latenser BA. Critical care of the burn patient: the first 48 hours. *Crit Care Med* 2009; 37:2819–26.

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19. Stengel D, Bauwens K, Sehouli J, et al. Emergency ultrasound-based algorithms for diagnosing blunt abdominal trauma. *Cochrane Database of Syst Rev*. 2005; (2):CD004446. doi: 10.1002/14651858.CD004446.pub2.

20. Sasser SM, Hunt RC, Faul M, et al; Centers for Disease Control and Prevention. Guidelines for field triage of injured patients: Recommendations of the National Expert Panel on Field Triage, 2011. *MMWR Recomm Rep*. 2012;61(1):1-21.

21. American College of Surgeons. Hartford Consensus Compendium. *Bulletin of the American College of Surgeons*. 2015;100(1S):1-88

Suggested Websites

1. Society of Critical Care Medicine. www.sccm.org

2. American Burn Association. www.ameriburn.org
3. Burn Surgery. www.burnsurgery.org. Brain Trauma Foundation www.braintrauma.org
4. American Association for the Surgery of Trauma. www.aast.org
5. Centers for Disease Control and Prevention – Data & Statistics. www.cdc.gov
6. Eastern Association for the Surgery of Trauma. www.east.org
7. Trauma.org. www.trauma.org
8. World Society of the Abdominal Compartment Syndrome. www.wsacs.org
9. American College of Surgeons. www.facs.org

ACUTE CORONARY SYNDROMES

Objectives

- Identify patients who have acute coronary syndromes with various electrocardiographic and clinical presentations.
- Outline diagnostic procedures and the acute management of non–ST-elevation acute coronary syndrome (NSTE-ACS), and ST-elevation myocardial infarction (STEMI).
- Identify appropriate reperfusion interventions for patients with STEMI and high-risk patients with NSTE-ACS.
- Recognize the complications of myocardial infarction and outline the appropriate management.

Case Study

A 68-year-old man with a long-standing smoking history, type 2 diabetes, and hypertension develops sudden-onset severe chest pain associated with difficulty breathing and diaphoresis. His vital signs on arrival in the emergency department are as follows: blood pressure 158/94 mm Hg, heart rate 98 beats/min, respiratory rate 28 breaths/min, and oxygen saturation measured by pulse oximetry 97% on room air. His physical examination is remarkable only for a fourth heart sound (S4) and mild diaphoresis.

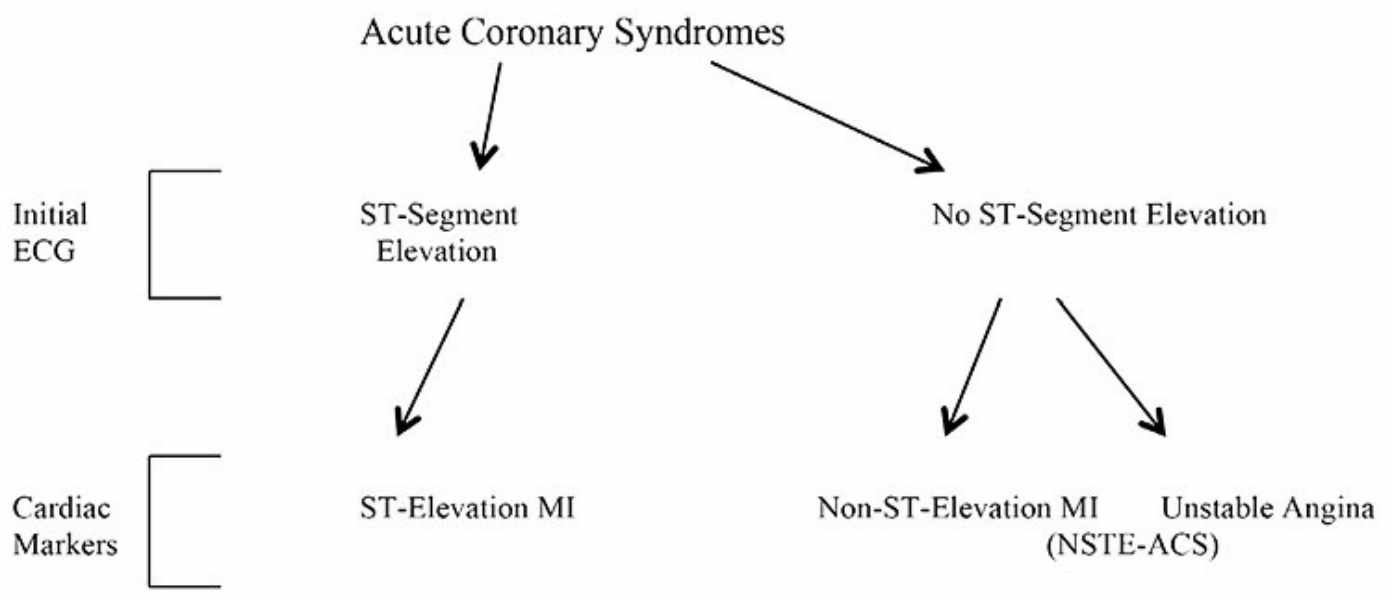
– What information is needed to determine if this patient has an acute coronary syndrome?

– What immediate interventions should be performed?

I. INTRODUCTION

Acute coronary syndrome (ACS) refers to a group of symptoms indicative of acute myocardial ischemia covering the spectrum of clinical conditions ranging from unstable angina, non–ST-elevation myocardial infarction (NSTEMI) and ST-elevation myocardial infarction (STEMI) [**Figure 10-1**]. An important distinction is made clinically between patients with ACS who have ST elevation on an electrocardiogram (ECG) and those who do not. Patients with ST elevation should be considered for immediate reperfusion.

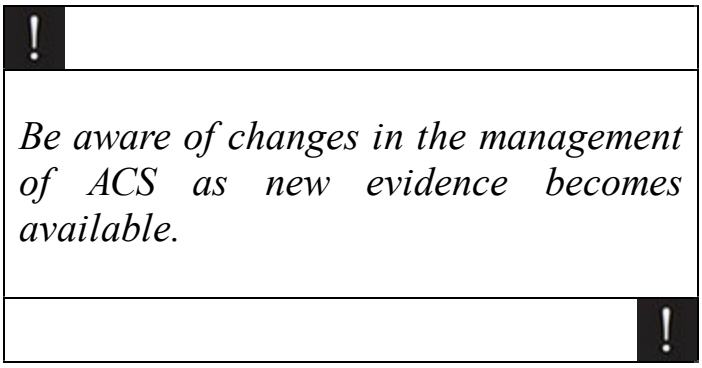
Figure 10-1. Overlapping Spectrum of Acute Coronary Syndromes



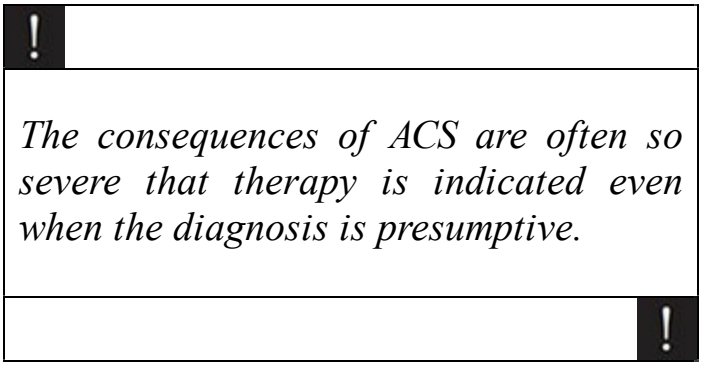
Abbreviations: ECG, electrocardiogram; NSTE-ACS, non-ST-elevation acute coronary syndrome; MI, myocardial infarction Acute coronary syndromes are distinguished by initial ECG findings and cardiac markers.

Unstable angina and NSTEMI are grouped together as non–ST-elevation acute coronary syndrome (NSTE-ACS). They differ in the severity of ischemia and myocardial damage. Damage resulting in elevation of biochemical markers of myocardial injury establishes the diagnosis of NSTEMI. Although unstable angina and NSTEMI are managed initially with pharmacologic interventions, high-risk patients may also require an invasive strategy with urgent reperfusion. Unstable angina and NSTEMI are characterized pathologically by various degrees of coronary artery occlusion that result in decreased myocardial oxygen supply relative to myocardial oxygen demand. Rupture or erosion of atherosclerotic plaques leads to a complex process of inflammation, platelet activation and aggregation, thrombus formation, and microembolization to the distal vasculature. The patient's specific syndrome depends on the severity and duration of occlusion. Myocardial ischemia less commonly results from severe anemia or hypoxemia that

limits myocardial oxygen delivery.



Hospitals should establish multiprofessional teams (including primary care physicians, emergency medicine physicians, cardiologists, nurses, and others) to develop evidence-based protocols for triaging and managing patients with symptoms suggestive of ACS. These protocols must be updated periodically based on the best current evidence.



Identification of patients at risk for ACS is based on an assessment of risk factors for coronary artery disease (**Table 10-1**) and detection of previous myocardial ischemia.

Table 10-1	Risk Factors for Coronary Artery Disease
Family history of myocardial infarction	Obesity
Hypertension	Diabetes mellitus
Smoking history	Other vascular disease
Hyperlipidemia	Sedentary lifestyle
Increasing age	Cocaine/amphetamine use
Postmenopausal state	

Patients with other critical illness or injury have an increased risk for ACS and frequently have atypical presentations. Definitive diagnosis of ACS often is not possible on initial evaluation and requires continuous observation, electrocardiographic (ECG)

monitoring, and/or laboratory evaluations. The initial physical examination should include vital signs and general observation, assessment of jugular venous distension, auscultation of the lungs and heart, evaluation of the peripheral pulses, detection of neurologic deficits, and assessment for evidence of systemic hypoperfusion.

II. NON–ST-ELEVATION ACUTE CORONARY SYNDROME

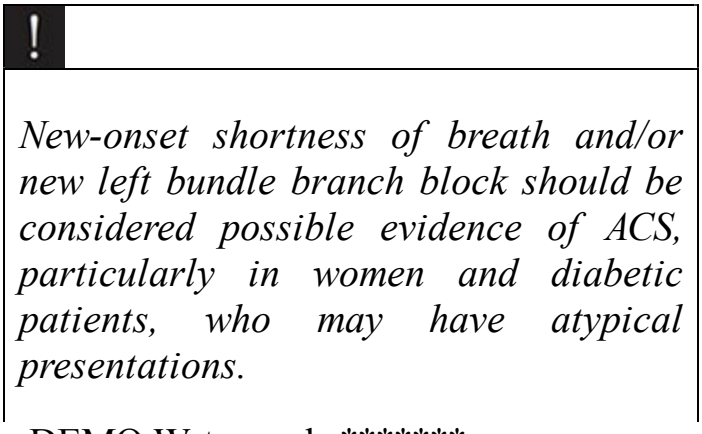
At presentation, patients with ischemic-type chest pain and an ECG with no ST-segment elevation are presumed to have NSTE-ACS. Other causes of prolonged chest pain (**Table 10-2**) should also be considered. Based on serial ECGs and levels of biochemical markers of cardiac injury, patients are subsequently diagnosed with an NSTEMI or unstable angina.

Table 10-2	Differential Diagnosis of Prolonged Chest Pain

Acute myocardial ischemia
Aortic dissection/aortic aneurysm
Myocarditis
Pericarditis
Pain associated with hypertrophic cardiomyopathy or esophageal and gastrointestinal disorders
Pulmonary diseases such as pneumothorax, pulmonary embolism, and pleuritis
Hyperventilation syndrome
Aortic stenosis
Musculoskeletal or chest wall diseases, costochondral pain
Psychogenic pain

Adapted with permission from the Agency for Healthcare Research and Quality. Braunwald E, Mark DB, Jones RH, et al. Unstable angina: diagnosis and management. AHCPR Publication 94-0602. Rockville, MD: Agency for Health Care Policy and Research and National Heart, Lung, and Blood Institute; 1994.

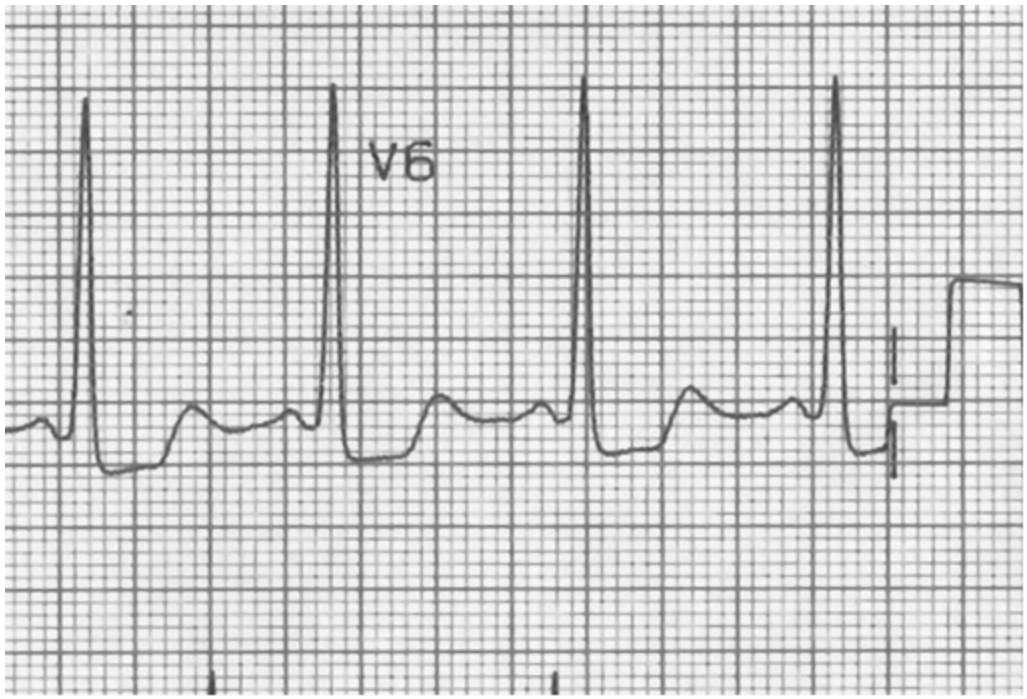
A. Diagnosis



New-onset shortness of breath and/or new left bundle branch block should be considered possible evidence of ACS, particularly in women and diabetic patients, who may have atypical presentations.

The most important factors that suggest the likelihood of myocardial ischemia are the character of the pain, prior history of coronary artery disease, age, and number of risk factors. Results of the physical examination may be normal, although a fourth heart sound (S_4) may be heard during episodes of pain. A 12-lead ECG should be obtained and interpreted as soon as possible by prehospital personnel to facilitate diagnosis, triage, and treatment. If this ECG was not obtained earlier, it should be done and interpreted within 10 minutes of the patient's arrival at the hospital. The ECG is most helpful if it shows transient ST-segment depression (**Figure 10-2**) during anginal episodes—but it may be normal, or it may reveal nondiagnostic T-wave inversions or peaked T waves. The history, findings from physical examination, ECG interpretation, and cardiac biomarkers should be used in the diagnosis of NSTE-ACS and in assessing the patient's short-term risk of an adverse outcome, such as death or nonfatal myocardial ischemia (**Table 10-3**).

Figure 10-2. Electrocardiogram of a Patient With NSTE-ACS[a]



The ST-segment depression in lead V_6 is characteristic of non-ST-elevation acute coronary syndrome.

[a] Reproduced with permission of Shih-Chung Lin, MD.

Table 10-3	Risk Factors for Death or Nonfatal Myocardial Ischemia[a]	
High Risk (1 or more of the following)	**Intermediate Risk (No high risk factors**	**Low Risk (no high or intermediate**

	and 1 of the following)	risk factors and 1 of the following)
• Ongoing pain at rest (>20 min) • Pulmonary edema, S_3, or rales • Hypotension • Bradycardia, tachycardia • Age >75 y • Rest angina with dynamic ST-segment changes >0.05 mV • Elevated troponin (>0.1 ng/mL)	• Prolonged rest pain (>20 min) now resolved • Rest pain <20 min or relieved with nitroglycerin • Age >70 y • T-wave inversions >0.2 mV • Pathologic Q waves • Slightly elevated troponin (<0.1 ng/mL)	• Increasing frequency, severity, or duration of pain • Lower threshold for pain • Normal or unchanged electrocardiogram during pain • Normal troponin

[a]Adapted with permission from the Agency for Healthcare Research and Quality. Braunwald E, Mark DB, Jones RH, et al. *Unstable Angina: Diagnosis and Management*. Rockville, MD: Agency for Health Care Policy and Research and National Heart, Lung, and Blood Institute. US Public Health Service, US Department of Health and Human Services; 1994. AHCPR Publication 94-0602.

Several risk stratification scores have been developed and validated to assist in predicting the risk of death and ischemic events in NSTE-ACS. The GRACE 2.0 (Global Registry for Acute Cardiac Events) score (http://www.gracescore.org/WebSite/default.aspx?ReturnUrl=%2f) requires an app or a web-based calculator, whereas the TIMI (Thrombolysis in Myocardial Infarction) risk score can be easily determined at the bedside (**Table 10-4**). High-risk patients are considered to have a greater than 6% risk of dying within 6 months, and intermediate-risk patients have a 6-month mortality rate of 3% to 6%. This risk assessment has implications for the location of care, selection of medical therapy, and use of reperfusion interventions. B-type natriuretic peptide may provide additional prognostic information. Additional tests, such as hemoglobin/hematocrit, electrolytes, thyroid function, and arterial oxygen saturation, may be helpful in identifying a precipitating factor as conditions such as anemia, metabolic derangements, endocrine abnormalities, fever, infection, and inflammation may precipitate ischemic cardiac events.

Table 10-4	TIMI Risk Score for Adverse Cardiac Events
1 point for each: • Age ≥65 y • Known coronary artery disease (coronary stenosis ≥50%)	

- ST-segment deviation of at least 0.5 mm
- At least 2 angina events in prior 24 hours
- Use of aspirin in prior 7 days
- At least 3 risk factors for coronary artery disease (family history of premature coronary artery disease, hypertension, hyperlipidemia, diabetes, smoking)
- Elevated serum cardiac markers

Risk Level	Score	Risk of Adverse Cardiac Event
Low	0-2	5% to 8%
Intermediate	3-4	13% to 20%
High	5-7	26% to 41%

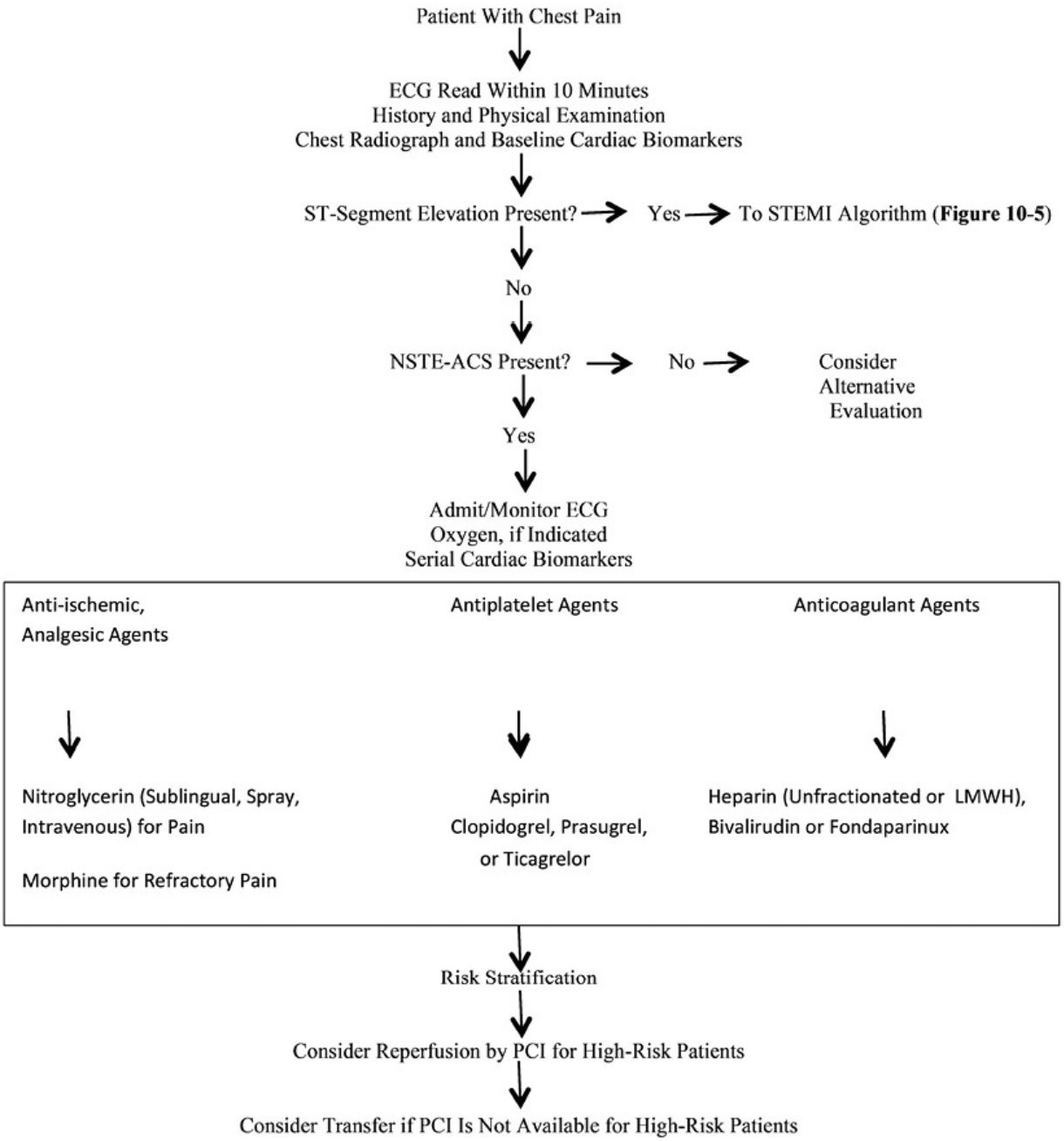
Abbreviation: TIMI, Thrombolysis in Myocardial Infarction

If equipment and expertise are available, the use of transthoracic echocardiography allows bedside assessment of wall motion abnormalities as a marker for current or past ischemia and the detection and follow-up of new abnormalities. It also provides an estimate of left ventricular function and identification of valvular dysfunction and/or pericardial fluid.

B. Management

Management of the patient with chest pain includes increasing myocardial oxygen delivery by improving perfusion and decreasing myocardial oxygen demand. Reversing myocardial ischemia and confirming the diagnosis of NSTE-ACS are the initial priorities. Patients with NSTE-ACS should be admitted to a unit with cardiac monitoring (eg, telemetry unit, chest pain or observation unit) and placed on bed or chair rest (see treatment algorithm in **Figure 10-3**). Oxygen (2-4 L/min by nasal cannula) should be administered to patients with dyspnea, hypoxemia (oxygen saturation measured by pulse oximetry <90% on room air), or evidence of heart failure or shock. Emerging data suggest that routine use of supplemental oxygen in cardiac patients with normal oxygenation may have untoward effects, including increased coronary vascular resistance, reduced coronary blood flow, and an increased risk of death. If precipitating, reversible causes — such as fever, anemia, hypoxemia, infection, hypertension, anxiety, hyperthyroidism, arrhythmias, or sympathomimetic drug ingestion (eg, cocaine, amphetamines) — can be identified, they should be treated aggressively. Further management includes relief of pain and anti-ischemic therapy, therapy for platelet aggregation/thrombosis, ongoing risk stratification, and consideration of invasive reperfusion procedures.

Figure 10-3. Treatment Algorithm for Non−ST-Elevation Acute Coronary Syndrome



Abbreviations: NSTEMI, non-ST-elevation myocardial infarction; NSTE-ACS, non-ST-elevation acute coronary syndrome; ECG, electrocardiogram; MI, myocardial infarction; LMWH, low-molecular-weight heparin; PCI, percutaneous coronary intervention

1. Pain relief and analgesia

Pain relief is an important element in the early management of the patient with NSTE-ACS. Management should be directed toward acute relief of symptoms of ongoing myocardial ischemia and general relief of anxiety and apprehension. Immediate control

of ischemic pain is typically accomplished with a combination of nitrates and opiate agents. Antianginal medications that are effective in stabilizing patients with unstable angina are listed in **Table 10-5**. The goal is to reduce ischemia without causing hypotension or reflex tachycardia. Patients with ongoing ischemic discomfort should receive up to three doses of sublingual or spray nitroglycerin. Nitrates should not be administered if the systolic blood pressure measures <90 mm Hg or ≥30 mm Hg below the patient's baseline blood pressure. Additional contraindications to nitrate administration are heart rate <50 beats/min, tachycardia >100 beats/min in the absence of heart failure symptoms and in suspected right ventricular infarction or severe aortic stenosis. If sublingual or spray nitroglycerin does not relieve pain, an assessment should be made about the need for IV nitroglycerin for persistent ischemia. Excessive decreases in blood pressure with nitroglycerin are predominantly due to increased venous capacitance and can often be treated with careful IV crystalloid infusion. If the mean arterial pressure decreases by more than 25% when hypertension is present or if the systolic pressure falls below 110 mm Hg in normotensive patients, the nitroglycerin dose should not be increased. Instead, a second antianginal agent should be administered. Tolerance to the hemodynamic effects of nitroglycerin becomes important after 24 hours of continuous infusion, and efforts should be made to switch to other dosing regimens. The dose of IV nitrates should be tapered and discontinued when ischemic manifestations have resolved for 12 to 24 hours. Nitrates are contraindicated in patients who have received a phosphodiesterase inhibitor for erectile dysfunction in the previous 24 hours (48 hours for tadalafil). Morphine sulfate is a reasonable analgesic for management of pain refractory to initial antianginal therapy. Nonsteroidal anti-inflammatory drugs, other than aspirin, and COX-2 inhibitors should not be initiated and should be discontinued during hospitalization because of the potentially increased risk for major adverse cardiac events, especially with long-term use.

Table 10-5 Anti-ischemic Therapy

Agent	Oral Dose	Spray Dose	Intravenous Dose
Nitroglycerin	0.3- to 0.4-mg tablet sublingually to a maximum of 3 doses; contraindicated when systolic blood pressure <90 mm Hg	0.4 mg every 5 min to a maximum of 3 doses; contraindicated when systolic blood pressure <90 mm Hg	Initial infusion rate 10 μg/min; increases of 10 μg/min every 3-5 min as needed to control pain; discontinue rate increases for significant drops in blood pressure or maximum of 200 μg/min
Morphine sulfate			1-5 mg every 5-30 min as needed for pain
β-blockers			
Propranolol	20-80 mg every 6-8 h		0.5-1 mg as a single dose
Metoprolol	50-100 mg every 12 h		5 mg every 5 min to a total dose of 15

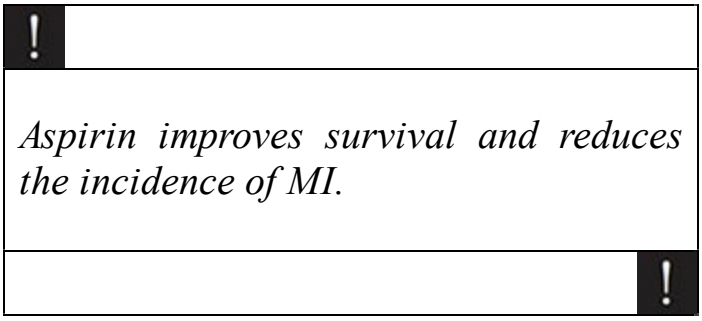
		mg
Atenolol	50-200 mg every 24 h	5 mg every 10 min to a total dose of 10 mg
Carvedilol	6.25 mg every 12 h titrated to maximum 25 mg every 12 h	
Diltiazem	30-60 mg every 6-8 h	

Oral β-blockers should be initiated within the first 24 hours in patients with no contraindications to their use (**Table 10-6**). Routine use of IV β-blockers in the initial management of patients with suspected NSTE-ACS is not supported by current evidence, but may be considered in patients with ongoing chest pain, especially with concomitant hypertension or tachycardia; IV dosing should be followed by oral administration. Caution is advised with the use of IV β-blockers in patients with risk factors for shock (age >70 years, heart rate >110 beats/min, systolic blood pressure <120 mm Hg, or late presentation).

Table 10-6 Contraindications to β-Blocker Use in Acute Coronary Syndromes

Heart rate <50 beats/min
Moderate to severe left ventricular dysfunction (uncompensated)
Shock or increased risk for cardiogenic shock
Marked first-degree atrioventricular block (with PR interval >0.24 s)
Second-degree or third-degree heart block (without a cardiac pacemaker)
Systolic blood pressure <90 mm Hg
Peripheral hypoperfusion
Active bronchospastic disease (asthma or chronic obstructive pulmonary disease)

Non-dihydropyridine calcium channel blockers (eg, diltiazem, verapamil) do not reduce the risk of myocardial infarction (MI). In the absence of contraindications (such as significant left ventricular dysfunction), they may be considered only if patients cannot tolerate a β-blocker or symptoms are not controlled with nitroglycerin and β-blockers together.



2. Antiplatelet therapy

The use of antiplatelet and anticoagulant agents (**Table 10-7**) is important in patients with NSTE-ACS because of the contributions of platelet activation/aggregation and the coagulation system to platelet-rich thrombus formation. Three classes of antiplatelet drugs may be of benefit in acute myocardial ischemia: aspirin, adenosine diphosphate inhibitors (eg, clopidogrel, prasugrel, and ticagrelor), and glycoprotein (GP) IIb/IIIa inhibitors. The intensity of therapy with these agents is often tailored to the patient's risk assessment and to plans for early invasive procedures. Non−enteric-coated aspirin at a dose of 162 to 325 mg should be administered (and chewed) as soon as possible to all patients with NSTE-ACS (including those in the prehospital setting) if no aspirin allergy is suspected. Aspirin should be administered indefinitely. Clopidogrel or ticagrelor should be considered as an alternative antiplatelet agent if aspirin is contraindicated. If an early invasive strategy or noninterventional conservative approach is planned, clopidogrel or ticagrelor should be added to aspirin to decrease the risk of cardiovascular death, MI, and stroke. Clopidogrel, prasugrel, or ticagrelor should be administered in patients undergoing percutaneous coronary interventions (PCIs), but prasugrel is contraindicated in those with a prior history of stroke or transient ischemic attack and is associated with an increased risk of bleeding. The choice of a specific adenosine diphosphate inhibitor should be discussed with the cardiologist when possible. Therapy with an adenosine diphosphate inhibitor is recommended for at least 12 months.

Table 10-7 Antiplatelet Drugs Used in Acute Coronary Syndromes

Antiplatelet Agents	
Aspirin	162-325 mg chewed and swallowed initially, then 81-325 mg as a minimum oral dose daily
Adenosine diphosphate inhibitors (thienopyridines)	
Clopidogrel	Loading dose of 300 mg orally can be used with a noninvasive approach or fibrinolysis; loading dose of 300 to 600 mg orally with PCI; maintenance dose of 75 mg orally daily
Prasugrel	Loading dose of 60 mg orally may substitute for clopidogrel in patients with STEMI managed with early PCI who are not at high risk of bleeding; maintenance dose of 10 mg daily (consider 5 mg daily if weight <60 kg); not studied for STEMI treated with fibrinolysis
Ticagrelor	Loading dose of 180 mg orally may be an option instead of clopidogrel in NSTE-ACS or STEMI managed with early PCI; maintenance dose of 90 mg twice daily; not studied for STEMI treated with fibrinolysis

Abbreviations: PCI, percutaneous coronary intervention; STEMI, ST-elevation myocardial infarction; NSTE-ACS, non−ST-elevation acute coronary syndrome

Selected high-risk patients (those with continuing ischemia, elevated troponin levels)

may be candidates for additional antiplatelet therapy with GP IIb/IIIa inhibitors when an early invasive strategy is chosen. However, the benefit of GP IIb/IIIa inhibitors may be limited when dual antiplatelet therapy (aspirin and an adenosine diphosphate inhibitor) and anticoagulation are instituted. A cardiologist should be consulted regarding selection and initiation of a GP IIb/IIIa inhibitor. Baseline coagulation and platelet studies should be completed before the administration these agents.

3. Anticoagulant therapy

The combination of aspirin and an anticoagulant agent is more beneficial than aspirin alone in NSTE-ACS. The selection of a specific agent should take into account the risks of ischemia and bleeding complications, as well as the presence of renal dysfunction. In ACS patients treated with a conservative ischemia-guided approach, low-molecular-weight heparin, unfractionated heparin, bivalirudin, or fondaparinux should administered as soon as possible unless there are significant contraindications. Patients managed with fondaparinux require an additional anticoagulant to prevent catheter thrombosis if a PCI is subsequently performed. Unfractionated heparin is continued at least 48 hours, and enoxaparin or fondaparinux for the duration of the hospital stay (up to 8 days), in patients managed with medical therapy or until PCI is performed. If an early invasive strategy is planned, unfractionated heparin, enoxaparin, or bivalirudin should be initiated as soon as possible. Serial platelet counts are required to monitor for heparin-induced thrombocytopenia. Argatroban is an alternative anticoagulant in patients with known heparin-induced thrombocytopenia. Patients who are adequately anticoagulated with warfarin still require antiplatelet therapy, but anticoagulation with heparin or alternative agents is generally not needed unless the international normalized ratio is less than 2.0.

4. Reperfusion interventions

Fibrinolytic agents have no proven efficacy in NSTE-ACS. Most patients with NSTE-ACS can be medically stabilized, and consultation can then be obtained for further risk stratification and/or invasive strategies (cardiac catheterization). Patients who have NSTE-ACS but no serious comorbidities and who have refractory angina, hemodynamic or electrical instability, or other high-risk indicators (**Table 10-8**) are candidates for an immediate or early invasive strategy. An immediate cardiology consultation should be obtained for patients who cannot be medically stabilized or who have serious comorbidity. Patients with NSTE-ACS and shock benefit from early reperfusion with PCI or coronary artery bypass graft and should be triaged to the catheterization laboratory as soon as possible.

Table 10-8	Elevation Acute Coronary Syndrome

Refractory angina
Recurrent angina at rest or with minimal exertion despite therapy
Hemodynamic instability
Signs or symptoms of heart failure
Signs or symptoms of new or worsening mitral regurgitation
Sustained ventricular tachycardia or ventricular fibrillation
Very high prognostic risk (high TIMI or GRACE score)
Temporal change in troponin level
New ST-segment depression

Abbreviations: TIMI, Thrombolysis in Myocardial Infarction; GRACE, Global Registry for Acute Cardiac Events

5. Other interventions

An angiotensin-converting enzyme (ACE) inhibitor or angiotensin receptor blocker should be administered in the first 24 hours to patients with NSTE-ACS and evidence of pulmonary congestion or left ventricular ejection fraction <40% unless contraindications are present. In addition, a statin should be initiated or continued after consideration of contraindications. Aldosterone blockade is an option in patients receiving an ACE inhibitor and β-blocker who have an ejection fraction <40%, diabetes or heart failure, and no contraindications. Risk-factor modification, including weight reduction and information about smoking cessation, is recommended in all cases of ACS.

III. ST- ELEVATION MYOCARDIAL INFARCTION

Patients with STEMI have a high likelihood that a thrombus occludes a coronary artery, resulting in a wave front of myocardial necrosis that begins at the endocardial surface within 15 minutes. The infarction progresses outward to the epicardium over approximately 6 hours unless collateral flow, spontaneous reperfusion, or reperfusion via an intervention is established. This progression may be modulated by the extent of collateral flow and determinants of myocardial oxygen consumption, which affords an opportunity for myocardial salvage. As with the patient with NSTE-ACS, prompt diagnosis and early treatment of the patient with STEMI have great influence on morbidity and mortality rates.

A. Diagnosis

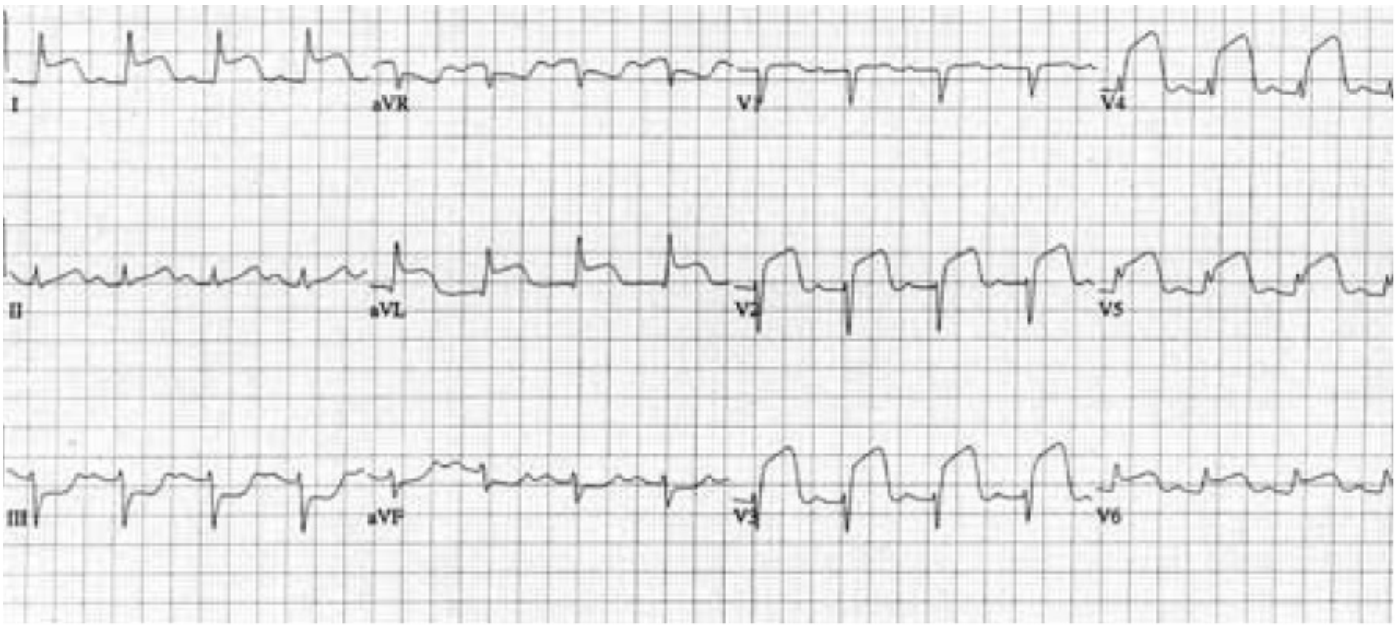
Patients with STEMI typically present with prolonged chest pain and associated

symptoms, but some patients have MIs that are painless (silent infarction/ischemia) or have other related symptoms, such as dyspnea and fatigue. In the critically ill patient population, STEMIs may not be associated with classic symptoms and are often suspected when complications occur, new arrhythmias develop, or ECG changes are noted. The physical examination findings are nonspecific.

The most common finding in patients with normal sinus rhythm is the S_4 heart sound, indicating decreased left ventricular compliance at the end of ventricular filling. Bibasilar crackles due to pulmonary edema may be present and are helpful in assessing the hemodynamic status. A brief, focused physical examination aids in the diagnosis and assessment of possible complications of STEMI. A limited neurological examination for evidence of prior stroke or cognitive deficits also should be conducted.

When possible, a prehospital 12-lead ECG should be obtained and interpreted to facilitate diagnosis, triage, and treatment on arrival at the medical facility. Otherwise, a patient with chest discomfort or symptoms suggestive of ACS should have this ECG performed and read within 10 minutes of arrival or detection of symptoms. The ECG is diagnostic of STEMI in the absence of QRS confounders (ie, bundle branch block, pacing, left ventricular hypertrophy, Wolff-Parkinson-White syndrome) if it shows ≥2 mm of ST-segment elevation in 2 or more contiguous leads in men or ≥1.5 mm of ST-segment elevation in women in leads V_2-V_3 and/or ≥1 mm in other contiguous leads (**Figure 10-4**).

Figure 10-4. ECG Indicating an Anterolateral STEMI



This electrocardiogram (ECG) shows classic findings of ST-elevation in the anterior (V_2 through V_4) and lateral (I, aVL, V_5, V_6) leads, indicating an anterolateral ST-elevation myocardial infarction (STEMI).

Reproduced with permission from Barbara McLean.

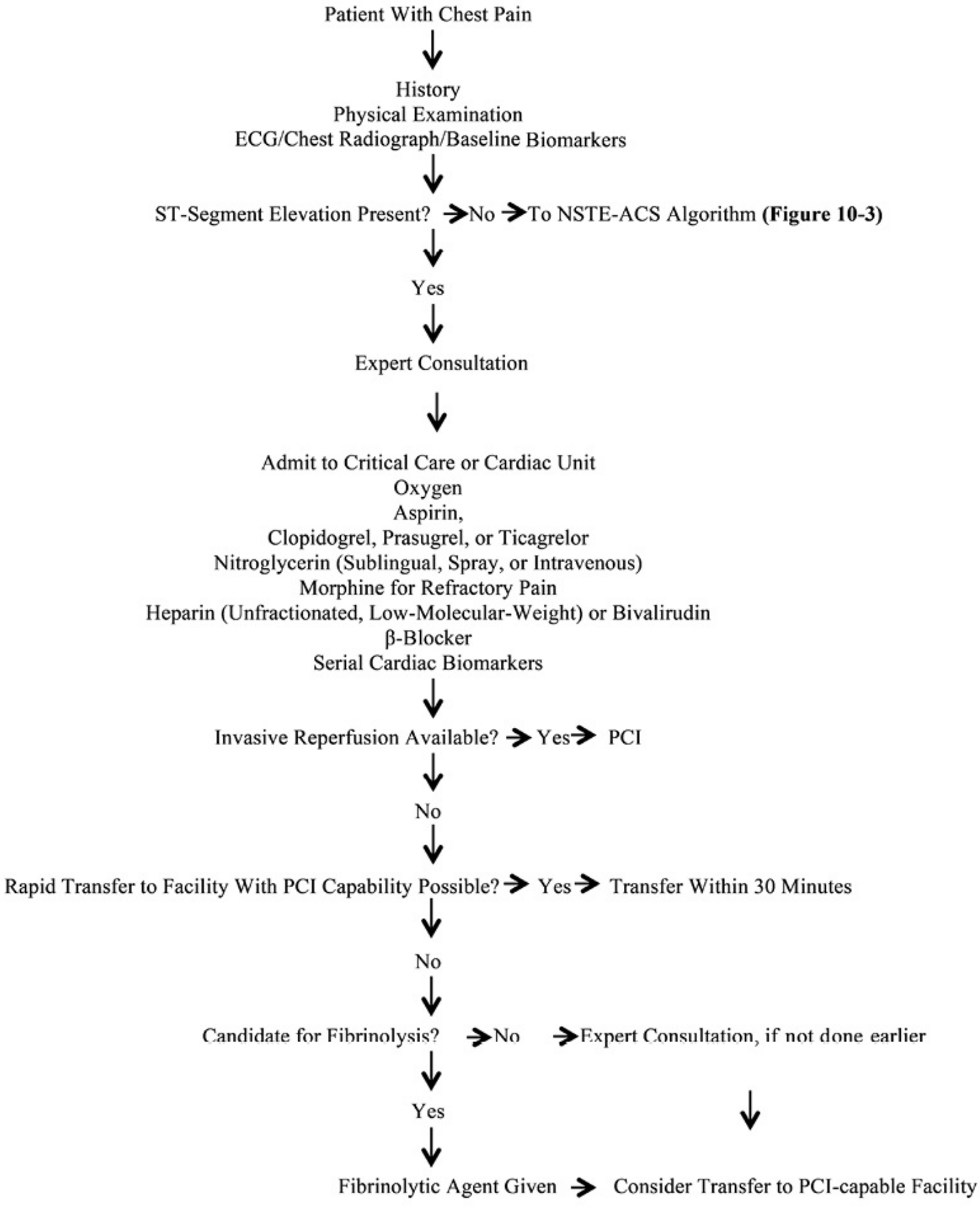
A right-sided ECG is indicated in patients with an inferior STEMI to determine if ST-segment elevation suggesting right ventricular infarction is present. Patients with ECG findings of new or undiagnosed left bundle branch block and chest pain compatible with myocardial ischemia are treated similarly to those with ST-segment elevation. If the initial ECG is not diagnostic but the patient remains symptomatic with a high clinical suspicion for ischemia, serial ECGs at 5- to 10-minute intervals or continuous 12-lead ST-segment monitoring (if available) may be performed to detect the development of ST-segment elevation.

If the diagnosis is in doubt, echocardiography may add helpful information by showing focal wall motion abnormalities The diagnosis is confirmed by elevated serum levels of cardiac-specific troponins. The delay in elevation of these markers, however, prevents their use in determining reperfusion therapy.

B. General Management

Once STEMI is suspected or diagnosed, the immediate concerns are to ensure the patient's hemodynamic stability and to limit infarct size by restoring blood flow to the affected artery as soon as possible (**Figure 10-5**). Cardiology expertise should be sought promptly. Treatment of STEMI in the patient with other critical illness requires careful individualization. Absolute and relative contraindications to therapies must be considered and relative risk assessed. Choices may be limited by the availability of specialized procedures, the need to transport the patient to another facility, significant comorbidities, bleeding risk, or the unavailability of the oral route for administering medication.

Figure 10-5. Treatment Algorithm for Myocardial Infarction With ST-Elevation



Abbreviations: ECG, electrocardiogram; PCI, percutaneous coronary intervention.

1. Early Therapy

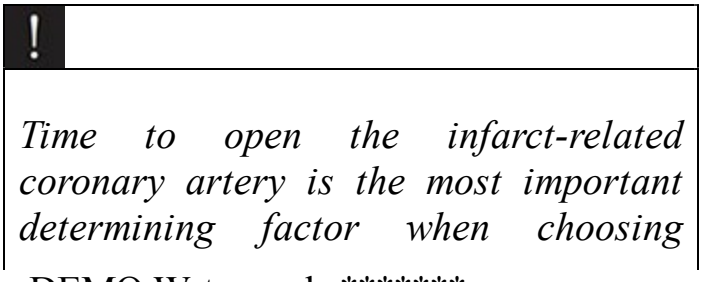
Early therapy in STEMI is similar to the management of NSTE-ACS. Immediate 12-lead ECG, cardiac-specific troponin measurement, and related laboratory tests should be completed. Immediate therapy includes the administration of supplemental oxygen in the presence of dyspnea, hypoxemia, heart failure, or shock; the control of pain; and consideration of reperfusion therapy. Aspirin should be administered immediately. The addition of a loading dose and subsequent maintenance doses of clopidogrel or ticagrelor as part of dual antiplatelet therapy decreases the rates of mortality and major vascular events. An anticoagulant agent, unfractionated heparin or bivalirudin, should also be administered to patients undergoing PCI. Intravenous nitroglycerin may be useful in patients with STEMI and ongoing chest pain, hypertension, or heart failure, unless the systolic blood pressure is below 90 mm Hg. Intravenous β-blockers are not routinely administered but may be considered at presentation if hypertension or ongoing ischemia is present and there are no contraindications.

2. Acute Reperfusion Therapy

Early reperfusion of the infarct-related coronary artery is associated with improved survival in patients with STEMI. Prompt restoration of flow can be achieved by primary PCI, fibrinolysis, or surgical intervention. The percutaneous procedure is clearly preferred if it can be done in a timely fashion. A plan for early reperfusion in patients with STEMI should be developed based on the resources available in the facility and community.

a. Percutaneous Coronary Interventions

PCIs include angioplasty, usually with deployment of an intracoronary bare-metal or drug-eluting stent, along with pharmacologic measures to prevent thrombosis. Primary PCI results in higher patency rates of the infarct-related coronary artery and lower rates of recurrent ischemia, reinfarction, and death. Primary PCI is the preferred reperfusion technique if the procedure can be performed by experienced personnel within 12 hours of symptom onset. It is also preferred with clinical or electrocardiographic evidence of ongoing ischemia, even if more than 12 hours have elapsed since symptom onset. A goal of 90 minutes or less from hospital presentation to balloon inflation is optimal.



options for reperfusion.

Primary PCI is particularly preferred over fibrinolysis for patients with contraindications to fibrinolysis or at a high risk of bleeding, for patients with STEMI and severe heart failure or cardiogenic shock, and for patients in whom the diagnosis of MI is in doubt. If primary PCI is not available, transfer to a facility with invasive reperfusion capability should be initiated as soon as possible (preferably within 30 minutes).

In general, the higher the patient's mortality risk (as with large infarctions, heart failure or hemodynamic instability, previous infarctions, or acute left bundle branch block), the more primary PCI is preferred. Similarly, the higher the risk of fibrinolysis, the more primary PCI is preferred. Conversely, the longer the time required for performance of PCI or transfer to another facility, the more fibrinolysis may be preferred. Patients presenting within 3 hours of the onset of symptoms who have a low risk of bleeding appear to derive particular benefit from prompt reperfusion with fibrinolytic therapy. Transfer for PCI is preferred over fibrinolysis in patients who present 3 to 12 hours after onset of symptoms if transfer can be accomplished in a timely manner. For patients who fail to reperfuse after fibrinolytic therapy, PCI is recommended, even if it requires transfer to another institution.

Pre-procedure management should include all of the strategies for ACS outlined previously. The use of an adenosine diphosphate inhibitor and an IV anticoagulant agent (unfractionated heparin or bivalirudin) before PCI is recommended. A loading dose of clopidogrel, prasugrel, or ticagrelor should be administered as soon as possible before PCI. Additional boluses of unfractionated heparin may be needed during the procedure. Bivalirudin may be used with or without prior unfractionated heparin administration. The addition of a GP IIb/IIIa inhibitor may be considered by the cardiologist in selected patients. Potential complications of an invasive strategy for treating STEMI include problems with the arterial access site; adverse reactions to volume loading, the contrast medium, and antithrombotic medications; technical complications; and reperfusion events.

PCI is not contraindicated by the presence of coma or a need for targeted temperature management after cardiac

arrest.

Regardless of the reperfusion strategy chosen, timely implementation by experienced personnel is optimal. Routine use of PCI in the first 2 to 3 hours after fibrinolytic therapy is not recommended. In the event of cardiac arrest from ACS, local protocols for treatment of acute MI and coronary reperfusion, including targeted temperature management (TTM), should be activated. Even in the absence of ST-elevation, medical or interventional treatments may be considered for the treatment of ACS.

b. Fibrinolysis

Ideally, thrombolytic therapy should be initiated within 30 minutes of the patient's arrival to the hospital.

If PCI is not available or cannot be performed within 120 minutes of arrival, fibrinolytic therapy should be considered. Limitation of infarct size is optimized when fibrinolytics are administered within 6 hours of symptom onset, but they may have some benefit as long as 12 hours after symptom onset. The physician must weigh the potential risks against the benefits of fibrinolysis for each patient. If the decision to proceed is made and no absolute contraindications exist (**Table 10-9**), fibrinolytic therapy should be administered expeditiously. Several agents are available, and all are effective (**Table 10-10**). Findings that suggest reperfusion include relief of symptoms, maintenance or restoration of hemodynamic and/or electrical stability, and reduction of at least 50% of the initial ST-segment elevation injury pattern on a follow-up ECG performed 60 to 90 minutes after the initiation of therapy. STEMI patients who develop cardiogenic shock or severe heart failure, or who have evidence of reperfusion failure or reocclusion after fibrinolytic therapy, should be transferred to PCI-capable facilities as soon as possible. Patients with STEMI who are hemodynamically stable and achieve successful reperfusion also should be considered for transfer to a PCI-capable facility. Antiplatelet and anticoagulant therapy is continued after fibrinolysis and before transfer.

Table 10-9 Contraindications for Fibrinolytic Therapy

Absolute Contraindications
Prior intracranial hemorrhage
Known cerebral vascular lesion
Ischemic stroke within past 3 months
Allergy to the agent
Significant head or facial trauma within past 3 months
Known intracranial neoplasm
Suspected aortic dissection
Active internal bleeding or bleeding diathesis (except menstruation)
Intracranial or intraspinal surgery within past 2 months
Severe uncontrolled hypertension (unresponsive to urgent therapy)

Relative Contraindications
Severe uncontrolled hypertension on presentation (blood pressure >180/110 mm Hg)
History of chronic, severe, poorly controlled hypertension
Ischemic stroke >3 months ago or intracerebral pathology
Current use of oral anticoagulants
Traumatic or prolonged (>10 min) cardiopulmonary resuscitation
Major surgery within past 3 weeks
Previous use of streptokinase/anistreplase: allergy or prior exposure (>5 days ago)
Active peptic ulcer disease
Recent internal bleeding (within past 2-4 weeks)
Noncompressible arterial or central venous puncture
Pregnancy

Table 10-10 Fibrinolytic Agents Used in ST-Elevation Myocardial Infarction

Streptokinase	1.5 million units intravenously over 30-60 min
Alteplase	15 mg intravenous bolus, then 0.75 mg/kg (maximum 50 mg) intravenously over 30 min, then 0.50 mg/kg (maximum 35 mg) intravenously over 60 min
Reteplase	10 units intravenously over 2 min followed in 30 min by 10 units intravenously over 2 min
Tenecteplase	Intravenous bolus adjusted for weight (30 mg if <60 kg; 35 mg if 60-70 kg; 40 mg if 70-80 kg; 45 mg if 80-90 kg; 50 mg if >90 kg)

3. Continuing Therapy

Patients who undergo PCI with angioplasty, with or without stent placement, should be treated with aspirin, an adenosine diphosphate inhibitor (clopidogrel, prasugrel, or ticagrelor), and an anticoagulant agent. Administration of clopidogrel or an alternative agent should be discussed with the cardiologist because the optimum duration may vary with the type of stent used. Anticoagulation with heparin is continued. Bivalirudin, a direct thrombin inhibitor, may be considered as an alternative to heparin. After fibrinolysis with a plasminogen activator, heparin should be used to maintain vessel patency for at least 48 hours. Enoxaparin is preferred over unfractionated heparin following fibrinolysis. Infusion rates of unfractionated heparin should be adjusted to

keep the partial thromboplastin time at 1.5 to 2 times the control value. Heparin anticoagulation after use of streptokinase is not necessary; fondaparinux, a factor Xa inhibitor, can be considered in these situations. Heparin should be used in patients with large anterior infarctions who do not receive fibrinolysis or PCI and in those who have intramural thrombus detected or suspected on echocardiography. Aspirin (81-325 mg/day) should be continued. Clopidogrel is the antiplatelet agent of choice in patients treated with fibrinolytics who undergo delayed invasive reperfusion interventions. Intravenous nitroglycerin may be useful in STEMI patients with hypertension or heart failure. In the absence of recurrent ischemia, heart failure, or arrhythmias, bed rest should not be continued beyond 12 to 24 hours.

Oral β-blockers should be initiated in the first 24 hours after the patient with STEMI has stabilized. Long-term use of these agents is helpful in all patients who are at risk for recurrent cardiovascular events and who have no contraindications to their use (**Table 10-6**).

Use of ACE inhibitors decreases the risk of death in all patients with STEMI. The greatest benefit is seen in those with left ventricular dysfunction (ejection fraction <40%), anterior infarction, or pulmonary congestion. ACE inhibition should be started within the first 24 hours of the infarction with low doses of oral agents unless hypotension (systolic blood pressure <100 mm Hg) or other contraindications are present. An angiotensin receptor blocker may be administered if the patient cannot tolerate an ACE inhibitor. High-dose statin therapy should be initiated early after hospital admission.

Long-acting calcium channel blockers may be a useful secondary therapy for recurrent myocardial ischemia but are not appropriate for first-line treatment. Immediate-release nifedipine is contraindicated in treatment of an acute MI. Diltiazem and verapamil are contraindicated in patients with STEMI and left ventricular dysfunction and heart failure.

Expert consultation should be obtained, and transfer to facility providing a higher level of care is indicated for patients who have persistent ischemic symptoms after MI, who develop cardiogenic shock, who have heart failure despite aggressive therapy, or who have recurrent ventricular fibrillation or tachycardia despite aggressive antiarrhythmic therapy.

C. Complications

Common early complications of MI are heart failure and cardiogenic shock, recurrent ischemia and/or infarction, and arrhythmias. Urgent cardiology consultation should be

obtained as soon as possible to assist with management and decisions regarding advanced interventions

1. Heart Failure and Cardiogenic Shock

Bedside evaluation allows accurate determination of a patient's hemodynamic status (**Table 10-11**) and the need for hemodynamic monitoring and intervention. Patients with Killip classes I and II heart failure can be managed without advanced hemodynamic monitoring but class III patients should be considered for this monitoring if they do not respond promptly to medical therapy. Class IV patients generally require advanced hemodynamic monitoring. Expert consultation should be sought and/or transfer arranged for patients with class III or IV findings. Advanced hemodynamic monitoring may also be warranted for those with suspected mechanical complications resulting in shock, such as papillary muscle rupture or dysfunction, ventricular septal defect, or cardiac tamponade.

Table 10-11 Killip-Kimball Hemodynamic Subsets

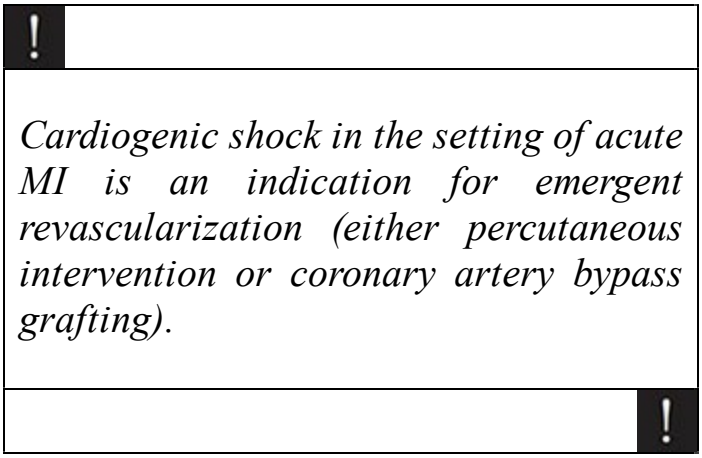
Class	Description
I	No dyspnea; physical examination results are normal
II	No dyspnea; bibasilar crackles or S_3 on examination
III	Dyspnea present; bibasilar crackles or S_3 on examination, no hypertension
IV	Cardiogenic shock

Pharmacologic treatment of heart failure should be tailored to the patient's clinical and hemodynamic state. Patients with systolic arterial pressure >100 mm Hg and low cardiac output should be treated initially with a vasodilator, either IV nitroglycerin or IV nitroprusside (doses of 0.3 to 1 μg/kg/min, titrated up in increments of 0.5 μg/kg/min every 10 minutes). If arterial pressure decreases or cardiac output remains inadequate, inotropic support with dobutamine should be initiated (1 to 2 μg/kg/min) and titrated to ≤15 μg/kg/min. Milrinone is an alternative inotropic agent with less arrhythmogenic effect than dobutamine, though it is often associated with hypotension. In countries where it is available, levosimendan has shown favorable hemodynamic benefits in cardiogenic shock. Loop diuretics, such as furosemide (20-40 mg intravenously or orally every 2-4 hours), should be used to reduce pulmonary congestion. Diuretics should be used with caution in hypotensive patients.

Patients with systolic arterial pressure <90 mm Hg and low cardiac output have cardiogenic shock. This hypotension should be treated with norepinephrine to raise the pressure. Once it has stabilized to at least 90 mm Hg, dobutamine can be added to

further increase cardiac output and reduce the dosage of vasopressor.

Interventional therapy with assistive devices may be indicated in patients with pump failure who do not respond promptly to medical therapy. These devices can stabilize the hemodynamic status sufficiently to allow PCI or coronary bypass surgery. Expert consultation is needed to determine if the patient is a candidate for this type of intervention.



Cardiogenic shock in the setting of acute MI is an indication for emergent revascularization (either percutaneous intervention or coronary artery bypass grafting).

Evidence suggests that patients with STEMI who develop shock within 36 hours benefit from early invasive reperfusion regardless of the time delay from the onset of MI. In patients with 1- or 2-vessel disease, PCI is preferred. Patients who remain symptomatic and have 3-vessel disease or significant left main coronary artery disease should undergo urgent consultation for coronary bypass surgery. PCI should also be performed in STEMI patients with severe heart failure and/or pulmonary edema and onset of symptoms within 12 hours

a. Right Ventricular Infarction/Ischemia

Some patients have heart failure from ischemia of the right ventricle, which results in elevation of right atrial and right ventricular filling pressures and low cardiac output. These hemodynamic abnormalities result in characteristic clinical findings of hypotension, clear lung fields, and distended internal jugular veins. The ECG usually reveals an inferior infarction, and the ST segment in lead V_1 may be elevated in the absence of elevation in any other standard precordial lead. An ECG tracing of the right precordial leads should be obtained and may reveal characteristic ST-segment elevation, especially in V_4R. Initial therapy includes maintenance of right ventricular preload with volume expansion until the blood pressure is stabilized. Associated bradycardia or high-degree heart block may require chemical or electrical intervention. Agents that reduce preload should be avoided, such as morphine, nitrates, ACE inhibitors/angiotensin receptor blockers, and diuretics. If volume expansion is

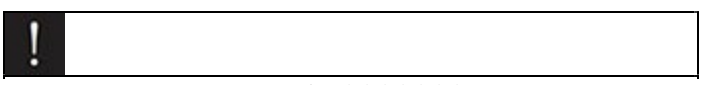
inadequate to stabilize the patient, inotropic support with dobutamine should be considered. Cardiology consultation should be obtained for assistance in managing patients with refractory hypotension.

b. Mechanical Complications

Serious mechanical complications following MI include ventricular free wall rupture, ventricular septal rupture, and acute mitral regurgitation, all of which typically occur during the first week after infarction. Urgent cardiology and/or surgical consultation is needed for these conditions. Although the incidence is low (<1%), ventricular free wall rupture is a serious, often lethal complication. Risk factors include an absence of collateral flow, anterior location of the infarct, use of corticosteroids or nonsteroidal anti-inflammatory agents, age >70 years, and female sex. Clinical presentation ranges from chest pain, nausea, and restlessness to sudden death. Echocardiography reveals pericardial effusion, and salvage is only possible following prompt recognition and thoracotomy for repair. Ventricular septal rupture presents as hypotension, severe biventricular heart failure, and cardiogenic shock with physical findings of a pansystolic murmur and parasternal thrill. Ischemic mitral regurgitation may be seen following an inferior MI due to compromised blood flow to the posterior papillary muscle. The typical presentation is that of acute-onset pulmonary edema and cardiogenic shock.

2. Recurrent Ischemia or Infarction

Recurrent ischemia or infarction occurs in up to 20% of patients treated with fibrinolytic therapy for MI, whereas patients receiving primary PCI have a lower incidence of recurrent ischemia. Ischemia after MI can be caused by residual stenosis in the infarct-related artery, by disease in another coronary artery, or by occlusion of a new stent. An ECG recorded during recurrent pain should be compared with those from the index MI event. Reinfarction may present special diagnostic difficulties because cardiac troponin levels can be elevated for 5 to 14 days. If the first blood sample reveals an elevated troponin value when recurrent ischemia is suspected, then serial levels of a cardiac marker with a shorter time course, such as creatine kinase MB, could be analyzed to clarify the possibility of recurrent infarction. No cardiac marker is reliable for the diagnosis of reinfarction in the first 18 hours after the onset of STEMI. However, if there is high suspicion for reinfarction, PCI should be considered regardless of cardiac biomarker values. Nonischemic etiologies, such as pericarditis and pulmonary embolism, should also be considered as potential causes of recurrent chest pain.



Detection of reinfarction is clinically important because it carries incremental risk for the patient.

Medical treatment of post-MI ischemia is similar to management of the initial MI but also includes cardiac catheterization and reperfusion, if possible. Acute reperfusion with PCI or coronary artery bypass graft may be required for stabilization.

3. Arrhythmias

Arrhythmias associated with ACS and reperfusion include atrial bradycardias, atrial tachycardias, atrioventricular (AV) blocks, ventricular tachyarrhythmias, and asystole. Hemodynamically significant atrial bradycardia or AV block can be treated initially with IV atropine in a dose of 0.5 mg every 3-5 minutes to a total dose of 3 mg while preparing for transcutaneous pacing. Atropine rarely corrects complete heart block or type II second-degree AV block. Temporary transvenous pacing is indicated for complete heart block, bilateral bundle branch block, new or indeterminate-age bifascicular block with first-degree AV block, type II second-degree AV block, and symptomatic sinus bradycardia that is unresponsive to atropine. Transcutaneous pacing should be initiated for patients who have indications for emergent temporary pacing until transvenous pacing can be instituted.

Atrial tachycardias, such as atrial fibrillation, may cause hemodynamic instability and precipitate myocardial ischemia, or they may be clinically insignificant and transient. Immediate cardioversion is indicated in unstable patients. Depending upon the specific arrhythmia, IV adenosine, β-blockers, diltiazem, digoxin, or amiodarone may be effective. Careful attention must be given to contraindications for any of these agents.

Ventricular tachycardia and ventricular fibrillation should be treated according to current advanced cardiac life support guidelines. After defibrillation and if indicated, amiodarone is the drug of choice in patients with an acute MI. Antiarrhythmic drugs are not recommended as prophylaxis for ventricular arrhythmias in the setting of acute MI. To aid in the prevention of post-infarction arrhythmias, prompt recognition and correction of systemic precipitants (including hypoxemia, acid-base abnormalities, and electrolyte disturbances) is recommended.

D. Special Considerations

1. Perioperative MI

Perioperative MI can occur before surgery, intraoperatively, and during the postoperative period. The latter is the most common, with the peak incidence on the third postoperative day. Perioperative MI is often associated with atypical presentations and is frequently painless; these patients rarely experience classic symptoms and signs of acute coronary syndromes. New-onset or increased atrial or ventricular arrhythmia is often the presenting finding, as is postoperative pulmonary edema. Other possible presentations may include hemodynamic instability and respiratory distress The diagnosis can be confirmed with serial ECG and cardiac marker determinations. Treatment is similar to standard treatment, except that fibrinolytic therapy may be contraindicated, depending on the type of surgery. Primary PCI should be considered for these patients.

2. Effects of Coexisting Diseases

Many, if not most, critically ill patients suffer from more than one medical condition that may require significant alterations in the standard therapeutic approach. Some have relative or absolute contraindications to standard medications or procedures. Patients with stress ulceration or gastritis may not be candidates for aspirin therapy. Postoperative patients or those with a bleeding diathesis may not be candidates for clopidogrel, heparin, fibrinolytic therapy, or aspirin. β-blockers should be avoided in patients with significant bronchospasm or decompensated heart failure. Certain drugs will need dose adjustments for renal or hepatic dysfunction. Critical illness of a non-cardiac origin may result in decreased oxygen delivery to the myocardium and subsequent myocardial dysfunction. Recommended management of multiple organ failure in critical illness focuses on supportive care and treatment of the underlying disease.

3. Targeted Temperature Management After Cardiac Arrest

Neurological injury is the most common cause of death in patients with out-of-hospital cardiac arrest. Patients who do not follow commands or have purposeful movements should receive TTM. Lowering the core body temperature to between 32°C and 36°C (89.6°F and 96.8°F) for 24 hours after cardiac arrest with appropriate supportive care can improve neurological outcome. TTM is associated with an increased risk of coagulopathy and infection.

Key Points

- The preliminary diagnosis of NSTE-ACS is based on the clinical symptoms, assessment of risk factors for coronary artery disease, and ECG interpretation.
- A 12-lead ECG should be obtained and interpreted within 10 minutes in patients with possible MI.
- For patients with suspected NSTE-ACS, perform risk stratification, select an initial management strategy, complete the diagnostic evaluation, and use medical therapy and revascularization as appropriate.
- Non–enteric-coated aspirin at a dose of 162 to 325 mg should be administered (and chewed) as soon as possible in all patients with suspected or diagnosed ACS.
- Antiplatelet and anticoagulant agents are important interventions in all patients with ACS.
- High-risk patients (continuing ischemia, elevated troponin levels) with NSTE-ACS may be candidates for additional therapy with an early invasive strategy.
- Oral β-blockers should be initiated in the first 24 hours for all patients with ACS unless there are strong contraindications present.
- A plan for early reperfusion of patients with STEMI should be developed based on resources available in the facility and community.
- Primary PCI is the preferred reperfusion technique if it can be performed by experienced personnel within 12 hours of symptom onset. Fibrinolytic therapy for reperfusion in STEMI ideally should be initiated within 30 minutes of the patient's arrival to the hospital if PCI cannot be performed.
- All patients with acute MI, whether or not they undergo reperfusion therapy, should be treated with aspirin and another antiplatelet agent, such as clopidogrel, prasugrel, or ticagrelor.
- Use of ACE inhibitors decreases the mortality rate in all patients with STEMI.
- PCI is not contraindicated in patients with coma or a need for targeted temperature management after cardiac arrest.
- Patients with cardiogenic shock in the setting of acute MI should undergo emergent revascularization.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Amsterdam EA, Wenger NA, Brindis RG, et al. 2014 ACC/AHA guideline for the management of patients with non-ST-elevation acute coronary syndromes: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines. *Circulation*. 2014;130:e344-e426.

2. Anderson JL, Adams CD, Antman EM, et al. 2012 ACCF/AHA focused update incorporated into the ACCF/AHA 2007 guidelines for the management of patients with unstable angina/non-ST-elevation myocardial infarction: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. *J Am Coll Cardiol*. 2013;61(23):e179-347.

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6. Van de Werf F, Bax J, Betriu A, et al. Management of acute myocardial infarction in patients presenting with persistent ST-segment elevation: the Task Force on the Management of ST-segment Elevation Acute Myocardial Infarction of the European Society of Cardiology. *Eur Heart J*. 2008;29:2909-2945.

7. O'Gara PT, Kushner FG, Ascheim DD, et al. 2013 ACCF/AHA guideline for the management of ST-elevation myocardial infarction: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. *Circulation* 2013;127:e362-e425.

8. Roffi M, Patrono C, Collet JP, et al. 2015 ESC guidelines for the management of

acute coronary syndromes in patients presenting without persistent ST-segment elevation. Task Force for the Management of Acute Coronary Syndromes in Patients Presenting without Persistent ST-Segment Elevation of the European Society of Cardiology (ESC). *Eur Heart J*. 2016;37:267-315.

9. Steg PG, James SK, Atar D, et al. ESC guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation. *Eur Heart J*. 2012;33:2569-2619.

Suggested Websites

1. American College of Cardiology. http://www.acc.org.
2. American Heart Association. http://www.americanheart.org.
3. European Society of Cardiology. http://www.escardio.org.
4. Global Registry of Acute Cardiac Events (GRACE). http://www.outcomes-umassmed.org/GRACE/default.aspx.
5. National Institute for Health and Clinical Excellence. http://www.nice.org.uk.
6. Thrombolysis Myocardial Infarction (TIMI) Study Group. http://www.timi.org.

LIFE-THREATENING INFECTIONS: DIAGNOSIS AND ANTIMICROBIAL THERAPY SELECTION

Objectives

- Understand and apply the terminology specific to life-threatening infections.
- List the risk factors for the development of infection.
- Identify systemic and site-specific clinical manifestations of life-threatening infections, and understand the diagnostic use of clinical laboratory testing.
- Describe the different clinical and epidemiologic variables used to guide the selection of antimicrobial therapy.
- Outline antimicrobial empiric therapy and treatment of specific infections.

Case Study

A 75-year-old nursing home patient was transferred to the emergency department because of change in mental status and abdominal pain. The nursing home staff reported that the patient has been having abdominal pain and loose stools for the last 24 hours. This morning he was found to have a change in mental status, where he was more lethargic. His vital signs at the emergency department showed a blood pressure of 90/60 mm Hg, heart rate of 120 beat/min, temperature 39°C (102.2°F), and respiratory rate 24 breaths/min with pulse oximetry 90% on 2-L nasal cannula. You are the responsible caregiver for the patient, and you are admitting the patient to the hospital.

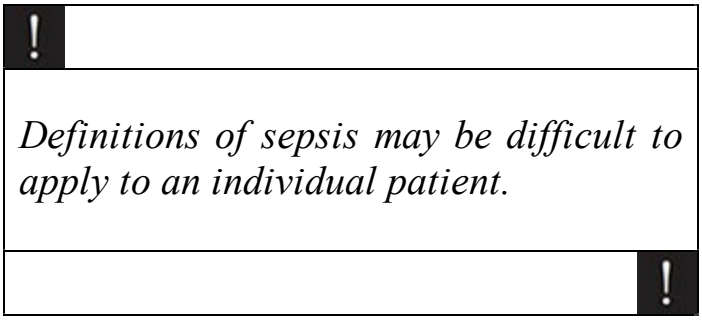
– Does this patient have sepsis?

– What level of care is needed for this patient?

– What initial immediate interventions should be instituted?

I. INTRODUCTION

Life-threatening infections are both a cause and a consequence of critical illness. The incidence of life-threatening infections or sepsis is increasing as a reflection of the growing population of patients at risk: the elderly, immunocompromised patients, and those with malignancy, chronic illness, or multiple trauma. Septic shock, the most severe form of systemic response to infection, is a common cause of death in critically ill adults and children. Early recognition and appropriate management of infections and their sequelae can decrease the mortality rate.



Sepsis is defined as life-threatening organ dysfunction caused by host response to infection. Abnormalities that suggest organ dysfunction may include, but are not limited to, lactic acidosis, oliguria, coagulation disorders, and an acute alteration in mental status. These abnormalities are not specific for sepsis and may be present in other conditions. *Septic shock* is identified in the clinical setting of sepsis with hypotension requiring vasoactive drugs to maintain mean arterial pressure >65 mm Hg and having a serum lactate level >2 mmol/L despite adequate fluid administration. Patients with suspected infection who are likely to have a prolonged ICU stay or die in the hospital can be identified at the bedside by alteration in mental status, systolic blood pressure <100 mm Hg, or a respiratory rate of >22 breaths/min.

Initial considerations in resuscitation and infection management are described in **Chapters 6** and **7**.

II. DIAGNOSIS OF INFECTION

The diagnosis of serious or life-threatening infection is based on a careful and complete assessment of the patient's history, including risk factors, and the presence of characteristic clinical manifestations. Atypical presentations that may occur, particularly in the elderly and in the immunocompromised patient, must also be considered. Laboratory, microbiologic, and imaging results also support the diagnosis

of documented or suspected infection.

A. Evaluation of New Fever in Critically Ill Adult Patients

In some ICUs, the measurement of a newly elevated temperature triggers an automatic order set that includes tests that are sometimes unnecessarily time consuming, costly, and disruptive to the patient and staff. Moreover, the patient may experience discomfort, be exposed to unneeded radiation, require transport outside the controlled environment of the ICU, or lose considerable blood to this testing, which is often repeated several times within 24 hours and daily thereafter. In an era when utilization of hospital and patient resources is under intensive scrutiny, such fevers should be evaluated in a prudent and cost-effective manner. A new fever in a patient in the ICU should trigger a careful clinical assessment rather than automatic orders for laboratory and radiologic tests. The goal of such an approach is to determine, in a directed manner, whether infection is present so that additional testing can be avoided and therapeutic decisions can be made.

Some literature defines fever as a temperature >38°C, whereas other sources define it as two consecutive measurements of >38.3°C. It is often difficult to determine whether an abnormal temperature is a reflection of a physiological process, a drug, or an environmental influence. When evaluating a new fever, an attempt should be made to rule out causes other than infection before subjecting the patient to a barrage of investigations. Additionally, not all infected patients are febrile. Evaluation should include a review the patient's chart, a thorough examination and review of all environmental factors as well as drugs that the patient has received recently, and consideration of physiological fever that can occur in patients in the ICU, such as postoperative fever. A new onset of temperature >38.3°C (≥100.9°F) or ≤36°C (≤96.8°F) in the absence of a known cause of hypothermia (eg, hypothyroidism, cooling blanket) is a reasonable trigger for a clinical assessment but not necessarily a laboratory or radiologic evaluation for infection. All of the patient's new medications and blood products should be considered. Ideally, the new drug should be stopped or a similar agent substituted. Fever induced by drugs may take several days to resolve.

If infection is suspected, the temperature in the ICU is most accurately measured by an intravascular, esophageal, or bladder thermistor, followed by rectal, oral, and tympanic membrane measurements. Axillary measurements, temporal artery estimates, and chemical dot thermometers should not be used in the ICU. Rectal thermometers should be avoided in neutropenic patients.

The diagnosis of drug-induced fever is usually established by the temporal relationship

of the fever to starting and stopping the drug. Patients can be rechallenged with the drug to confirm the diagnosis, but this is rarely done unless the drug in question is essential and alternatives are not available. Patients developing anaphylaxis or toxic epidermal necrolysis as a result of drug exposure should not be rechallenged.

Fever is a common phenomenon during the initial 48 hours after surgery. Fever in this early postoperative period is usually non-infectious in origin, presuming that unusual breaks in sterile technique or pulmonary aspiration did not occur. Considerable money can be wasted in over- zealous evaluation of early postoperative fever. However, 96 hours after surgery, fever is more likely to represent infection.

Surgical site infections alone account for approximately 25% of overall costs related to treatment of nosocomial infections. The rate of surgical site infection is approximately 3%. This varies based on the degree of contamination of the incision, the patient's medical comorbidities (eg, diabetes mellitus and obesity increase risk), whether surgery is prolonged or an emergency, and whether any antimicrobial prophylaxis is administered correctly (eg, appropriate narrow spectrum of activity, administration just before incision, and discontinuation within 24 hours [48 hours for cardiac surgery]).

B. EPIDEMIOLOGIC FACTORS

Serious or life-threatening infections may occur in patients from the community, long-term care facilities (ie, nursing homes), or hospital settings. Serious or life-threatening community-acquired infections include bacterial pneumonia, central nervous system (CNS) infections or meningitis, urosepsis, intra-abdominal sepsis due to a ruptured or obstructed viscus, or sporadic uncommon infections, such as necrotizing fasciitis. Patients from long-term care facilities share this spectrum but often have infections with more resistant pathogens, and they may develop device-related infections. Finally, hospitalized patients are exposed to antimicrobial-resistant flora and numerous invasive devices, and they have more comorbidities and greater severity of illness than the other populations.

Healthcare-associated infections are acquired while the patient is receiving treatment for other conditions within a healthcare setting. It is estimated that these infections are associated with almost 100,000 deaths annually in the United States. Infection could occur during the current hospitalization or an admission in the last 60 days, residence in a nursing home or extended-care facility, home intravenous antibiotic therapy or chemotherapy, and chronic dialysis or home wound care.

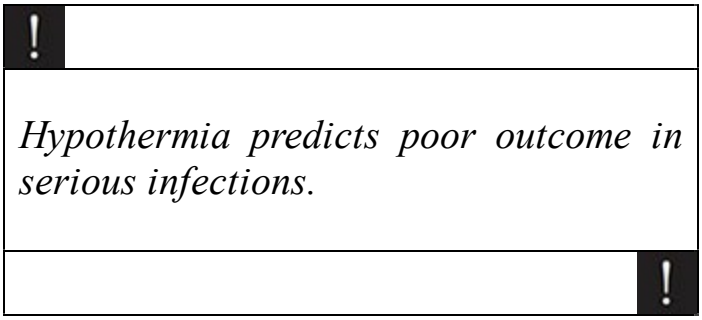
C. PREDISPOSING CONDITIONS

The presence of predisposing conditions should alert the care team to patients at higher risk of developing infections (**Table 11-1**). Permanent prosthetic implants, such as heart valves, intravascular grafts, or orthopedic devices, may become infected in either the early or late postoperative period. Invasive procedures (eg, surgery, vascular catheterization, placement of urinary catheters, and endotracheal intubation) breech the normal mucosal defense barriers and predispose patients to infection. The lack of predisposing conditions does not eliminate the possibility that a serious infection is present, particularly in patients admitted directly to the ICU from the community.

Table 11-1	Conditions Predisposing to Infection
Extremes of age	Diabetes
Transplant recipients	Hepatic failure
Multiple trauma	Malnutrition
Alcoholism	Malignancy
HIV	Corticosteroid use
Chemotherapy/radiotherapy	Burns
Absence of spleen	Prosthetic implants
Invasive procedures	

D. CLINICAL MANIFESTATIONS

The clinical manifestations of life-threatening infections are diverse, and they may be subtle or overt and localized or systemic. An awareness of the signs and symptoms associated with specific infections allows early recognition and prompt institution of appropriate empiric antimicrobial and supportive management. However, most of the clinical manifestations are not specific.



Hypothermia predicts poor outcome in serious infections.

1. Systemic Signs and Symptoms

Fever is the most frequent systemic manifestation of infection, but patients with serious infection may be normothermic or even hypothermic, particularly if they are elderly or if antipyretic medications, alcoholism, or renal or hepatic failure are involved. Temperature probes on a urinary catheter, when available, are the most reliable methods to measure the core temperature. Temperature measurement is most practically obtained via the oral or rectal routes, although the limitations of each method should be considered. Axillary temperatures are unreliable, and tympanic measurements have not been validated in the critically ill.

Other systemic manifestations include chills, rigors, hypotension, tachypnea, dyspnea, tachycardia, and nausea and vomiting. Tachycardia is almost always present but may be absent in the presence of cardiac conduction disturbances, autonomic dysfunction, β-blockers or calcium channel blockers, and drug fever. Hypotension may be due to dehydration and hypovolemia but may also indicate septic shock, particularly if the blood pressure does not respond to volume resuscitation. Hypoperfusion of the kidneys may result in oliguria or anuria. Encephalopathy is a common clinical manifestation and ranges from lethargy/irritability to delirium and coma. Petechiae and/or ecchymosis may be present, particularly on distal extremities.

2. Site-Specific Signs and Symptoms

Some signs and symptoms of infection could be associated with the specific source of infection:

- Infections of the CNS may be associated with headache, seizures, meningismus, or focal neurologic findings. Altered mental status is often present but not specific for CNS infections.
- Diffuse or localized respiratory tract infections may be associated with dyspnea, tachypnea, cough, sputum production, or (rarely) hemoptysis. Chest auscultation findings, such as crackles, rhonchi, or tubular breath sounds, indicate whether the process is localized or diffuse. Diminished breath sounds and dullness on percussion are suggestive of a pleural effusion.
- Intra-abdominal infections may cause abdominal pain, abdominal distension, nausea and/or vomiting, diarrhea, and anorexia. Diaphragmatic irritation can be perceived as pain in the side of the neck and proximal shoulder area or may cause hiccups. Findings on examination may include diffuse or local tenderness, rebound tenderness, ileus, or guaiac-positive stool. A wound infection with evidence of fascial disruption may signal an intra-abdominal infection below the fascia.
- Urinary tract infections may produce flank pain or abdominal pain, tenderness,

dysuria, hematuria, and oliguria. Typically, a urinary catheter–associated infection does not produce localized symptoms.

- Cutaneous manifestations may result from a primary infection of the skin or skin structures (eg, pain, erythema, and induration due to cellulitis; wound margin erythema; tenderness or purulent discharge; vesicular lesions due to herpes infection) or be a consequence of disseminated systemic infection (eg, erythematous indurated papules or nodules of ecthyma gangrenosum due to bacteremia, septic emboli due to infective endocarditis, diffuse macular erythema due to toxic shock syndrome, distal symmetric purpura fulminans due to meningococcemia).

E. Laboratory Manifestations

Routine laboratory tests are not specific in the diagnosis of life-threatening infections but may be suggestive and allow assessment of organ function. The white blood cell count is usually elevated with a shift to more immature forms (called a *left shift*). Leukocytosis is commonly observed in noninfectious processes such as the early postoperative period, corticosteroid therapy, massive transfusions, and polytrauma. Conversely, a normal leukocyte count may be observed despite active infection in the elderly and in patients with hypersplenism or chronic myelosuppressive disorders. Neutropenia may result from overwhelming infection (especially in neonates and AIDS patients), severe viral infection, typhoid fever, brucellosis, and other infections. Toxic granulation within neutrophils may also be noted.

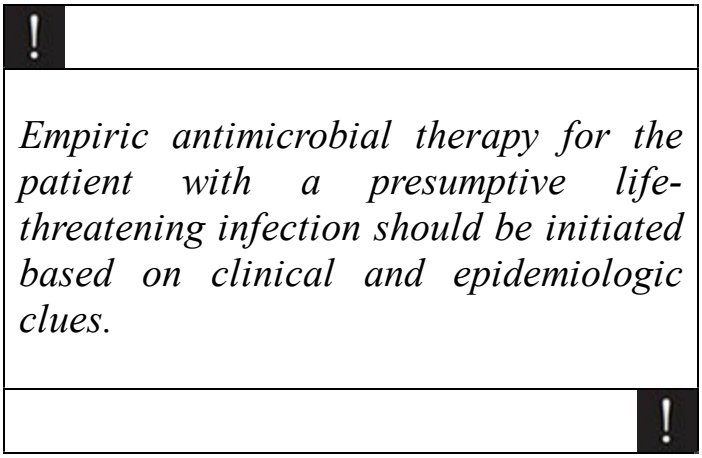
The most common coagulation abnormality in sepsis is isolated thrombocytopenia. A decline in platelet count may be a subtle, early clue to the presence of infection. Disseminated intravascular coagulation is a less common finding but is a poor prognostic sign. It is characterized by elevations in prothrombin time, partial thromboplastin time, fibrin split products, and/or D-dimer, and decreased fibrinogen.

Sepsis causes relative insulin resistance, usually resulting in hyperglycemia, whereas hypoglycemia is less frequent and often reflects low hepatic glycogen stores. Arterial blood gas measurements usually reflect metabolic acidosis, a low $Paco_2$ due to respiratory compensation and often hypoxemia. An elevated serum lactate level is a significant sign of compromised peripheral perfusion and oxygen balance due to severe sepsis or septic shock. Hepatic dysfunction is usually not severe but presents as a cholestatic picture with elevated bilirubin and mild elevation of transaminases. Renal insufficiency often occurs due to multiple factors, such as hypotension and hypovolemia. Other possible nonspecific markers of inflammation/infection include procalcitonin and

C-reactive protein.

F. Microbiologic Studies

Microbiologic studies are divided into those with immediately available results (minutes to a few hours) and those requiring a period for incubation or laboratory determination. Among the studies with quickly available results is Gram stain of body fluids. Special stains (such as fungal and acid-fast stains), immunoassays (such as urine *Legionella* antigen and *Clostridium difficile* toxins), and counterimmunoelectrophoresis panels require time to process.



Ideally, all cultures should be obtained before initiation or modification of antimicrobial therapy, but this may not be possible in the rapidly deteriorating patient. The selection of culture site(s) should be guided by clinical manifestations. Indiscriminate sampling from many sites not only may yield misleading results due to culture contamination or site colonization, but is also not cost-effective and may pose additional risks to the patient. Repeat cultures may be appropriate to assess for changes in the type of organism or resistance patterns.

At least two sets of peripheral blood cultures (aerobic and anaerobic bottles) should be obtained either from different anatomic sites or from the same site. A blood volume of 10 to 15 mL per culture set is optimal in adults. Obtaining blood cultures from indwelling peripheral or central intravascular catheters may yield false-positive results because of microbial contamination of the catheter hub. Isolator blood cultures may improve the diagnostic yield for some organisms (eg, *Candida*, *Mycobacterium*) or in patients already receiving antimicrobial therapy.

Respiratory tract cultures require expectorated sputum from the nonintubated patient and tracheal suction or bronchoscopic specimens from an intubated patient. Many microbiology laboratories will screen the specimen for the number of epithelial cells

and neutrophils to determine adequacy for culture. Quantitative cultures of lower respiratory tract secretions may discriminate between colonizing and pathogenic bacteria.

In the absence of catheterization, urine cultures should be clean-catch voided specimens; in catheterized patients, specimens should be aspirated from the urinary catheter tubing. If the catheter has been in place for few days, replacement is recommended and the culture obtained from the new catheter. Semiquantitative culture is needed; however thresholds for significance differ for clean-catch urine ($>10^5$ organisms/mL) and catheter-obtained urine (10^3 organisms/mL). Urinalysis for the detection of pyuria will help to discriminate bacteriuria from cystitis or upper tract infection.

Intravascular catheters should be removed (by applying chlorhexidine to the surrounding skin and external part of the catheter adjacent to the skin exit), and the catheter tip segment should be sent for semiquantitative culture. However, clinical correlation between the catheter culture result, blood culture(s), and appearance of the catheter exit site is required to discriminate between catheter-related bacteremia, local catheter-related infection, and simple colonization of the catheter itself. The best method for diagnosis of intravascular catheter-related bloodstream infections is the testing of paired cultures from peripheral and catheter blood samples.

III. ANTIMICROBIAL THERAPY

Case Study

A 70-year-old woman, status post laparoscopic cholecystectomy day 4, was scheduled to be discharged from the hospital the next morning. She was found sitting in bed, slightly confused, agitated, coughing, with evidence of vomitus around the mouth and on her clothing. The nurse evaluating the patient found that she was tachycardic and febrile, and her oxygen saturation was 88% on room air where previously it was 99%. The white blood cell count was elevated, and a chest radiograph confirmed new-onset pneumonia. You are asked to evaluate her.

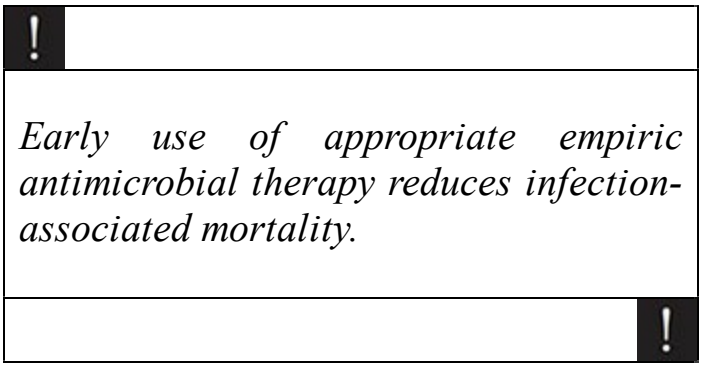
– What is the likely source of this patient's infection?

– What factors would influence your choice of antimicrobial agent?

The first priority in managing a hemodynamically unstable patient with a severe or life-

threatening infection is resuscitation (**Chapters 6** and **7**). After evaluation of the patient's history, physical examination, and auxiliary test results (laboratory and imaging studies), antimicrobial agents should be instituted promptly.

Early source control (suspected source of infection) is paramount to favorable outcomes and is an essential adjunct to adequate antimicrobial therapy. Examples of source control include wound debridement, percutaneous or surgical drainage of a closed-space infection, foreign body removal, and surgery. The antimicrobial therapy recommendations found in this chapter are general guidelines only. For each clinical scenario, antimicrobial choices must be individualized to match the clinical manifestations and the available epidemiologic and microbiologic information, including the patterns of microbial prevalence and resistance in the institution or local community.

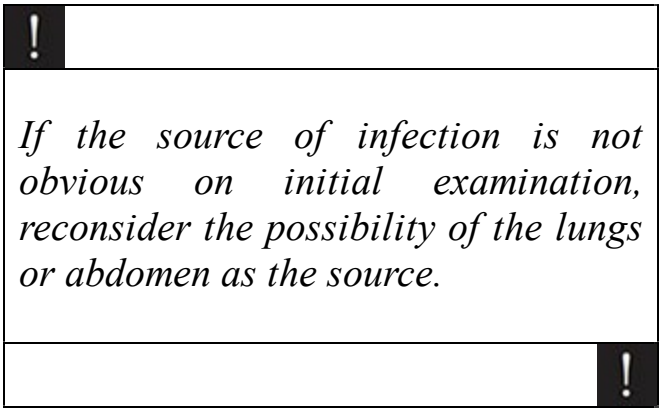


The selection of appropriate antimicrobial therapy depends on the following factors:

1. The suspected microbial pathogen(s) and site of infection: The most common sites for life-threatening infections in adult patients involve the lower respiratory tract, the intra-abdominal cavity, and the bloodstream. Rapidly progressive soft tissue infections and CNS infections should also be considered and are often clinically obvious. Antimicrobial penetration to the site of infection should also be considered. The CNS and lungs are two sites that allow limited penetration of certain antimicrobials; therefore, the pharmacokinetic characteristics of the selected agents must be understood to ensure maximal antimicrobial activity at those sites.

2. Gram stain results of available specimens from the suspected site: The description of early stain results directs the clinician to the broad categories of organism(s) that should be covered. Examples include gram-positive cocci in clusters (staphylococci) or pairs and chains (enterococci, streptococci), lancet-shaped diplococci (pneumococcus), gram-positive bacilli (*Corynebacterium*, *Nocardia*), gram-negative bacilli (*Escherichia coli*, *Klebsiella*, *Pseudomonas*), small

pleomorphic gram-negative bacilli (*Bacteroides* spp), gram-negative coccobacilli (*Haemophilus* spp, *Moraxella*, *Acinetobacter*), and yeast (*Candida*). However, the clinician should wait for final culture results to make changes to the initial antimicrobial therapy.



3. Assessment for antimicrobial resistance: Factors predicting that a particular bacterial pathogen may be resistant to a wider range of antimicrobials include the following:
   – Prior isolation of resistant strains from the same patient
   – Prior antimicrobial therapy (broad-spectrum antimicrobial therapy such as antipseudomonal penicillin/β-lactamase inhibitor combinations, third- and fourth-generation cephalosporins, fluoroquinolones, carbapenems, vancomycin)
   – Extended hospital or ICU stay
   – High endemic rate of multidrug-resistant bacteria in the institution or ICU (eg, methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant *Enterococcus*, multidrug-resistant *Pseudomonas*, *Stenotrophomonas*)
   – Ongoing epidemic outbreak in the hospital or ICU
   – Long-term dialysis
   – Residence in a nursing home or extended-care facility
   – Immunosuppressive diseases or therapy

Certain common organisms have become increasingly resistant to formerly effective antimicrobials. This category includes *Streptococcus pneumoniae* with intermediate- and high-level resistance to penicillin and ceftriaxone, *Enterococcus faecium* strains resistant to ampicillin and vancomycin, *S aureus* resistant to oxacillin/methicillin (methicillin-resistant *S aureus* [MRSA]), gram-negative bacilli (*E coli*, *Klebsiella pneumoniae*) with extended-spectrum β-lactamase or

chromosomal-mediated β-lactamase production observed in strains of *Pseudomonas aeruginosa*, or other mechanisms of multiple resistance to broad-spectrum antimicrobial therapy. It is vital to know and update the resistance pattern of the different bacterial pathogens in each institution and each ICU.

4. Comorbid conditions: Less nephrotoxic antimicrobials may be preferable in patients with diminished renal function or patients at risk for renal failure unless the benefit of use outweighs the risk of renal dysfunction. Other comorbidities to consider include bone marrow suppression, chronic or acute liver failure, prior hearing deficits, pregnancy, and a history of major hypersensitivity or other strong adverse reactions to a specific antimicrobial.

IV. RECOMMENDED ANTIMICROBIAL THERAPY

The use of the antimicrobial therapies recommended here is based on the suspected site of infection in the absence of culture results. The clinician should always consider the dose, dose adjustments, possible interactions, and side effects of selected agents. Antimicrobial therapy should be given in maximum appropriate therapeutic doses. In critically ill patients, intravenous administration is preferred to intramuscular or oral routes. Oral dosing of antimicrobials with similar bioequivalence (eg, quinolones) and adequate gastrointestinal absorption may be substituted after the patient stabilizes. Dosage adjustments must be made for the elderly, neonates, children, and patients with renal or hepatic dysfunction. Antimicrobial de-escalation should be implemented in appropriate clinical situations once cultures are negative. In the treatment of infection, antimicrobial agents must be used appropriately and responsibly. A list of selected site infections with empiric antibiotic therapy is found in **Table 11-2**.

Table 11-2 Site Infections and Empiric Antibiotic Therapies

Suspected Site of Infection	Possible Organism	Initial Empiric Antibiotics	Dose
Severe intra-abdominal infection (non-biliary)	*Pseudomonas*, extended spectrum β- lactamase-producing Enterobacteriaceae, *Acinetobacter*, multidrug-resistant GNB, *Bacteroides* spp	Imipenem-cilastatin, meropenem, or piperacillin-tazobactam or combination of cefepime and metronidazole	Imipenem-cilastatin, 500 mg IV q6h Meropenem, 1 g IV q8h Piperacillin-tazobactam, 4.5 g IV q6h Cefepime, 2 g IV q12h Metronidazole, 500 mg IV q8h
Urinary infection	*Escherichia coli, Pseudomonas*	Ceftriaxone or piperacillin-tazobactam	Ceftriaxone, 1 g IV daily Piperacillin-tazobactam,

	aeruginosa, and other GNB		4.5 g IV q6h
Lower respiratory infection	*P aeruginosa, E coli, Klebsiella pneumoniae, Acinetobacter* and other GNB spp, GPC like MRSA	Cefepime or carbapenem; vancomycin added whenever MRSA is considered	Cefepime, 2 g IV q12h Meropenem, 1 g IV q8h Vancomycin, 1 g IV q12h
Necrotizing soft tissue infection	Usually multi-microbial, GPC, GNB, and anaerobes	Vancomycin plus cefepime or carbapenem, and clindamycin	Cefepime, 2 g IV q12h Meropenem, 1 g IV q8h Clindamycin, 600 mg IV q8h Vancomycin, 1 g IV q12h
Gastrointestinal tract	*Clostridium difficile*	Metronidazole PO or IV, and vancomycin PO or rectally (if ileus)	Metronidazole, 500 mg PO or IV q8h Vancomycin, 125 mg PO q6h
Meninges, bacterial infection	*Streptococcus pneumoniae, Neisseria meningitidis, Listeria, Staphylococcus aureus*, and GNB following procedures (eg, shunt placement)	Ceftriaxone for *S pneumoniae*, ampicillin for *Listeria*, cefepime and vancomycin for others	Ceftriaxone, 1 g IV daily Ampicillin, 2 g IV q4h Cefepime, 2 g IV q8h Vancomycin, 1 g IV q12h

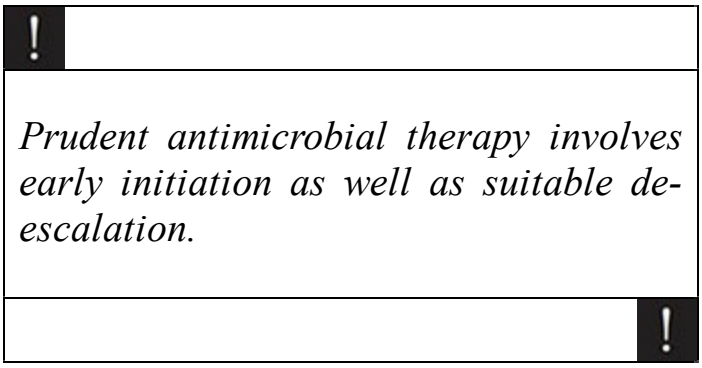
GNB, gram-negative bacilli; GPC, gram-positive cocci; MRSA, methicillin-resistant *S aureus*.

A. Central Nervous System

1. Meningitis

Bacterial meningitis causes one of the crucial emergencies. When it is suspected clinically, antimicrobial therapy should be instituted immediately, without waiting for the results of lumbar puncture. Community-acquired acute bacterial meningitis in adults is most commonly caused by *S pneumoniae* or *Neisseria meningitidis*, and initial empiric therapy with a third-generation cephalosporin (ceftriaxone or cefotaxime) provides adequate empiric coverage, with vancomycin added if penicillin-resistant *S pneumoniae* is suspected or confirmed. If *S pneumoniae* is isolated, a third-generation cephalosporin should be continued until penicillin sensitivity is confirmed, at which point the patient should be switched to high-dose penicillin G. *N meningitidis* in cerebrospinal fluid (CSF) or blood culture should be treated with high-dose parenteral penicillin G. If *N meningitidis* is isolated, healthcare workers with significant exposure require antimicrobial prophylaxis. In addition to antimicrobial therapy, adjunctive dexamethasone (0.15 mg/kg intravenously every 6 hours for 2-4 days) is also recommended to decrease the risk of morbidity and mortality, particularly in

pneumococcal meningitis.



Special circumstances require different empiric antimicrobial coverage. *Listeria monocytogenes* may be a cause of bacterial meningitis in extremes of age (neonates, infants, and the elderly) and in patients with T-lymphocyte defects, usually due to diabetes, corticosteroid use, and immunosuppressive therapy (eg, organ recipients and patients with autoimmune disease). Patients with suspected *Listeria* meningitis should receive ampicillin (trimethoprim-sulfamethoxazole in the penicillin-allergic patient). Those who have undergone recent neurosurgical procedures or placement of CSF shunts are at increased risk for *S aureus*, coagulase-negative staphylococci, and gram-negative bacilli (*Pseudomonas*, *Klebsiella*). Therefore, such patients require initial empiric antimicrobial coverage with high-dose vancomycin and a third- or fourth-generation cephalosporin. If methicillin-susceptible *S aureus* is confirmed, nafcillin is the drug of choice.

Meningitis presenting in a subacute fashion over several weeks or longer, with predominance of CSF lymphocytes, is more likely to occur in immunocompromised patients. Pathogens such as *Mycobacterium tuberculosis, Toxoplasma gondii*, and *Cryptococcus neoformans* should be considered in this setting.

2. Encephalitis or Meningoencephalitis

Many viral agents can cause encephalitis or meningoencephalitis, but only herpes simplex (HSV) and cytomegalovirus (CMV) encephalitis are amenable to therapy. Herpes simplex encephalitis usually occurs in immunocompetent individuals presenting from the community. This is considered an emergency. Fever, lethargy, confusion, and seizures are the most common presenting complaints. Hemorrhagic CSF and temporal lobe involvement on imaging studies (computed tomography or magnetic resonance imaging) or electroencephalography are suggestive of HSV encephalitis. Polymerase chain reaction testing of CSF is sensitive for diagnosis of this infection. If HSV encephalitis is suspected or confirmed, a 14- to 21-day course of parenteral acyclovir should be initiated promptly, pending further studies. CMV encephalitis usually occurs

in patients with suppressed immune status (HIV and transplant patients) and could have the same clinical manifestations as HSV encephalitis. Polymerase chain reaction testing of CSF for CMV is also highly sensitive, and therapy should include ganciclovir or foscarnet.

3. Brain Abscess

Brain abscess is an uncommon infection but should be suspected in patients with chronic infections of parameningeal structures, left-sided endocarditis, or congenital cyanotic heart disease. Brain abscesses also have been associated with immunosuppression, as in patients with AIDS, intravenous drug abusers, or transplant recipients. Infections are often polymicrobial, and etiologic organisms include aerobic and anaerobic streptococci, staphylococci, gram-negative bacteria, and anaerobes. Initial antimicrobial therapy should include vancomycin, high-dose metronidazole, and a third-generation cephalosporin (ceftriaxone). In patients at high risk for toxoplasmosis (eg, those with AIDS, cardiac transplant recipients), pyrimethamine/sulfadiazine should be part of the initial antimicrobial regimen. Less common causes of brain abscess include tuberculosis, nocardiosis, syphilis, amoeba, and other parasites. The diagnostic yield of CSF cultures for brain abscess is extremely low, and brain biopsy may be needed in patients who fail to respond to empiric therapy.

B. Respiratory Tract

1. Severe Community-Acquired Pneumonia (Immunocompetent Host)

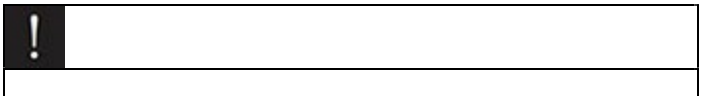
The most common organism resulting in hospitalization for community-acquired pneumonia is *S pneumoniae*, but other causative organisms include *Legionella*, *Mycoplasma*, and *Chlamydia*. *Haemophilus influenzae* is an uncommon pathogen in the United States because of the introduction of the vaccine against *H influenzae* type B in children. A β-lactam (ceftriaxone, cefotaxime, ampicillin-sulbactam) plus either a macrolide (azithromycin) or a respiratory fluoroquinolone are recommended in patients admitted to the ICU. If the patient is allergic to penicillin, a respiratory fluoroquinolone and aztreonam are recommended. If aspiration pneumonia is suspected (alcoholic patients, presence of poor dentition), the addition of clindamycin is warranted unless a β-lactam/β-lactamase inhibitor combination is utilized. If *Pseudomonas* is a consideration, an antipseudomonal β-lactam (piperacillin-tazobactam, cefepime, imipenem, or meropenem) should be used. Vancomycin or linezolid may be added if community-acquired MRSA is suspected.

2. Community-Acquired Pneumonia (Immunocompromised Host)

Immunocompromised patients with pneumonia may have the same pathogens as an immunocompetent host but with more severe infection. Radiographic evidence of interstitial pneumonia or a normal chest radiograph in a patient with prominent respiratory symptoms who has T-cell deficiency (AIDS, chronic steroid use) should prompt the addition of trimethoprim-sulfamethoxazole in appropriate doses for possible *Pneumocystis jirovecii* infection (The nomenclature for Pneumocystis species that infects humans has been changed from *Pneumocystis carinii* to *Pneumocystis jirovecii*). Consider the addition of steroids in *P jiroveci* pneumonia associated with significant hypoxemia. Focal lesions (eg, abscess, nodules) are suggestive of fungal infections, *M tuberculosis*, or *Nocardia*; empiric coverage with antifungal agents, antimycobacterial agents, and trimethoprim-sulfamethoxazole may be warranted in these circumstances. Patients with suspected *M tuberculosis* infection also require respiratory isolation. CMV or other viral infection also should be considered in the differential of an interstitial pneumonitis.

3. Nosocomial and Ventilator-Associated Pneumonia

Gram-negative organisms and *S aureus* are frequent causes of pneumonia in hospitalized patients or those who require mechanical ventilation. Nosocomial organisms tend to be more resistant and are more likely to be present in patients with extended hospital stays, prior antimicrobial therapy, and comorbidities. If possible, attempts should be made to obtain lower respiratory tract samples for quantitative microbiologic evaluation in mechanically ventilated patients. Adequate antimicrobial coverage can usually be provided with a third- or fourth-generation cephalosporin, β-lactam/β-lactamase inhibitor combinations, or a carbapenem, plus a fluoroquinolone or an aminoglycoside. If *Pseudomonas* is a consideration, an antipseudomonal β-lactam (piperacillin-tazobactam, cefepime, imipenem, or meropenem) should be used. Therapy with trimethoprim-sulfamethoxazole should be included if the possibility of *Stenotrophomonas maltophilia* is suspected or confirmed. Vancomycin should be considered if methicillin-resistant *S aureus* is a possible pathogen. Pneumonia due to methicillin-sensitive strains of *S aureus* should be treated with an antistaphylococcal penicillin as these agents are superior to vancomycin. Patients with methicillin-resistant *S aureus* who are vancomycin-intolerant or are not responding to vancomycin may be treated with linezolid. If vancomycin is utilized, serum trough levels should be maintained no lower than 15 to 20 μg/mL as lung penetration of this agent is limited. Shorter courses (8 days) of therapy may be appropriate as long as non-lactose-fermenting organisms are not isolated. Consideration may be given to stop the antibiotic therapy if the lower respiratory tract cultures are negative.



Utilize short courses of antimicrobial therapy when appropriate.

C. Heart

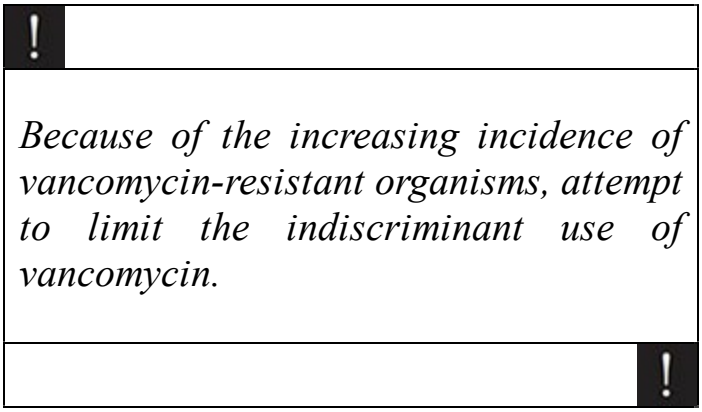
Infections of the heart are usually severe and life-threatening and require coordinated medical care with a cardiologist and sometimes with a cardiovascular surgeon. Microbiologic studies and echocardiography (transthoracic or transesophageal) are the cornerstones for the diagnosis and management of any infection in the heart.

Infective endocarditis, or infection of the endocardial surface of the heart, most frequently involves the heart valves. Intravenous drug abuse, prosthetic valves, sclerosing of natural valves due to aging, hospital-acquired infections, and newly identified pathogens (*Bartonella* spp, *Coxiella burnetii*, *Tropheryma whipplei*, fungi) are the main risk factors for this condition. Demonstration of bloodstream infection and positive echocardiographic evidence of valvular vegetations are key to making the diagnosis, although peripheral embolic phenomena and other findings are strongly suggestive. Gram-positive cocci, mainly *Staphylococcus* and *Streptococcus*, but also *Enterococcus*, are the most common microorganisms isolated in infective endocarditis in the general population and in specific risk groups (intravenous drug users and prosthetic valve endocarditis), but gram-negative, polymicrobial, fungal, and culture-negative cases of endocarditis are becoming more common. Bactericidal antimicrobial therapy (eg, penicillins/third-generation cephalosporins, daptomycin with or without an aminoglycoside, glycopeptides, linezolid), high drug concentrations, the resistance pattern of the microorganism, and long-term therapy are the cornerstones of treatment.

D. Intravascular Catheters

In patients with confirmed or suspected intravascular catheter infection associated with organ dysfunction, systemic emboli, or cardiovascular instability, the intravascular catheter should be removed promptly. In addition, local changes at the catheter site (purulence, erythema) mandate catheter removal. In the absence of local changes or sepsis, an option is to insert a new catheter in the existing site over a guidewire; however, this approach needs to be supported with negative blood cultures as well as negative culture of the intradermal portion of the removed catheter. Coagulase-negative *Staphylococcus* and *S aureus* are the most common pathogens in catheter-related bloodstream infections. In the immunocompetent patient who has a coagulase-negative

staphylococcal line infection but no systemic symptoms, the removal of the infected catheter line may be sufficient. Vancomycin is recommended in immunocompromised patients with coagulase-negative staphylococcal line infections, patients with systemic manifestations, or those with prosthetic devices at risk for becoming secondarily infected. If *S aureus* is the infecting organism, nafcillin is recommended; however, if there is a high rate of MRSA in the hospital or MRSA is confirmed, vancomycin should be used. Daptomycin can also be used; linezolid is less likely to be helpful. A third- or fourth-generation cephalosporin or fluoroquinolone should be added if a nosocomial gram-negative organism is suspected.



Because of the increasing incidence of vancomycin-resistant organisms, attempt to limit the indiscriminant use of vancomycin.

Candida is occasionally isolated from catheter tips and should increase the suspicion that occult candidemia may have been recently present. The treatment of choice is fluconazole; if there is a possibility of *Candida*, such as *Candida glabrata* or *Candida krusei*, caspofungin should be used. When a fungal microorganism is identified in an intravascular catheter-related bloodstream infection, a non-tunneled catheter always should be removed, whereas the removal of a tunneled catheter should be based on the likelihood of catheter-related candidemia rather than candidemia from another source. Antimicrobial-impregnated catheters appear to have a lower rate of bloodstream infection, but the maximum longevity of such catheters is still under investigation.

E. Abdomen

When an intra-abdominal infection is suspected, a surgeon must be involved in the evaluation of the patient. Both the infecting flora and the antimicrobial therapy are related to whether the infection was acquired in the community or healthcare setting. For community-acquired infections, location of a possible perforation determines the probable organism, with gram-positive, facultative, and aerobic gram-negative bacteria beyond the proximal small bowel and anaerobes beyond the proximal ileum. Recommended therapies include β-lactam/β-lactamase inhibitor combinations and carbapenems as monotherapy or cephalosporins/fluoroquinolones with metronidazole.

Antimicrobial therapy should be continued until clinical resolution, which typically occurs in 5 to 7 days. Further diagnostic workup should be pursued in patients with persistent or recurrent symptoms. Flora isolated from healthcare-associated intra-abdominal infections resembles that of other nosocomial infections. Antimicrobial therapy should be based on knowledge of the flora and antimicrobial susceptibilities of the institution. Anti-enterococcal therapy is indicated only when enterococci are isolated from patients with healthcare-associated infections. Antifungal therapy is indicated only in those who have isolated fungi and comorbid conditions – like recent immunosuppressive therapy for neoplasms, transplantation, and inflammatory disease – or who have postoperative or recurrent infections.

F. Urinary Tract

The most common pathogens in urinary tract infections are gram-negative enteric bacteria.Hospitalized patients with urinary catheters in place commonly have bacteriuria yet exhibit no pyuria or localized symptoms. Such patients (in the absence of urologic obstruction) rarely develop sepsis or bacteremia arising from the urinary tract, and removal of the catheter may allow resolution of the bacteriuria. Patients who develop upper urinary tract infection always merit antimicrobial therapy. More serious complications may be seen in diabetic patients or other immunocompromised individuals, including those with emphysematous pyelonephritis, papillary necrosis, or perinephric abscess, which may require surgical intervention. Empiric antimicrobial options for gram-negative urinary tract infections are dictated by susceptibility testing and include the following:

- Third-generation cephalosporins
- Aminoglycosides
- Piperacillin-tazobactam
- Trimethoprim-sulfamethoxazole

Enterococcal infection in the urinary system should be suspected in patients who have had urinary catheters in place for long periods or who have had recent manipulation of the urinary tract. Therapy should include ampicillin, piperacillin, or vancomycin.

Candiduria is not uncommon and usually occurs in patients who have long periods of urinary catheterization and are receiving broad-spectrum antimicrobial therapy or patients with glycosuria. Therapeutic options include a short course of fluconazole (not effective against *C glabrata* or *C krusei*) or continuous amphotericin bladder irrigation;

however, relapse rates are significant with either treatment. If candiduria is treated in a patient with an indwelling catheter, the catheter should be changed or removed during the treatment course.

G. Cutaneous Infection

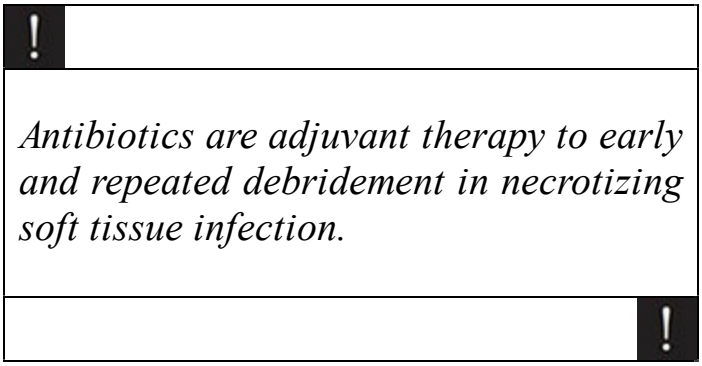
S aureus or group A β-hemolytic streptococci are the most likely etiologic organisms in cellulitis or cutaneous abscess. *H influenzae* must also be considered in facial or orbital cellulitis. Onset of postoperative wound infections usually occurs 5 to 7 days after surgery. However, rapidly progressive wound infections occurring within 24 to 48 hours after surgery should prompt the consideration of *Clostridium perfringens* or group A β-hemolytic streptococci (*Streptococcus pyogenes*). This type of infection warrants surgical debridement and prompt antimicrobial therapy directed by Gram stain and culture results. Antimicrobial choices include the following:

- Cefazolin or nafcillin if methicillin-resistant *S aureus* is unlikely
- Vancomycin or linezolid if there is a possibility of methicillin-resistant *S aureus*
- Penicillin G with or without clindamycin for wound infections developing within 48 hours to cover *C perfringens* and β-hemolytic streptococci
- Daptomycin because of its bactericidal properties

Wound toxic shock syndrome is a rare condition that can occur within 48 hours of a wound or surgical incision. The causes are toxin-producing *S aureus* or β-hemolytic streptococci, but often the wound does not appear infected. Presenting symptoms include fever, diarrhea, vomiting, hypotension, and uremia. Erythroderma and subsequent desquamation are characteristic but may be delayed for several days. Treatment involves opening the wound and prompt use of specific antimicrobial therapy.

H. Necrotizing Soft Tissue Infection

Infection of the subcutaneous tissue, fascia, and muscle can occur in any patient but may be more common in immunocompromised patients, particularly individuals with diabetes. If gas is present in the tissue, cutaneous gangrene or bullae are noted, or infection progresses rapidly, a necrotizing soft tissue infection must be considered. This condition requires prompt surgical debridement in addition to broad-spectrum antimicrobial therapy. These infections are usually polymicrobial, involving aerobic and anaerobic gram-positive and gram-negative organisms.



Adequate empiric therapy should include vancomycin and a β-lactam/β-lactamase inhibitor, a carbapenem and fluoroquinolone, or an aminoglycoside and clindamycin (the latter to reduce the amount of toxins).

I. Immunocompromised or neutropenic patients

In the absence of a specific source, pending culture results, broad-spectrum antimicrobial therapy is indicated in the immunocompromised or neutropenic patient with fever. Monotherapy can be effective, but combination therapy is indicated initially for more severely ill patients. To reduce the emergence of resistance, a third-generation cephalosporin as monotherapy should be avoided if *Pseudomonas* spp, *Acinetobacter* spp, *Enterobacter* spp, *Citrobacter* spp, or *Serratia* spp are prevalent.

Suggested antimicrobial regimens include the following:

- Third- or fourth-generation cephalosporin (ceftazidime or cefepime for *P aeruginosa* coverage) with an aminoglycoside or fluoroquinolones
- Carbapenems
- Piperacillin-tazobactam
- Addition of vancomycin if gram-positive organisms are likely

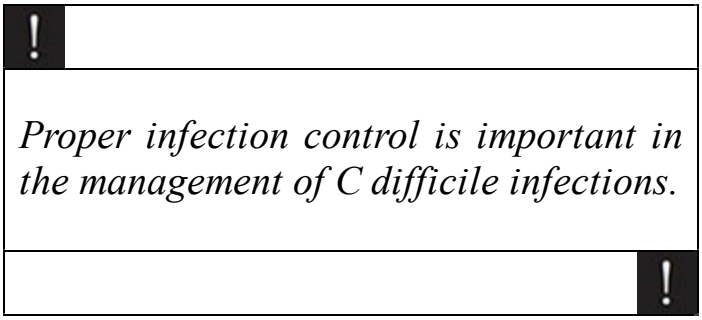
The use of white cell growth factors (ie, granulocyte colony-stimulating factor, granulocyte-macrophage colony-stimulating factor) may improve outcome by shortening the duration of neutropenia. These progenitor cell stimulants should be targeted for patients with an anticipated duration of neutropenia of 5 to 7 days and a high risk for serious infection.

J. Clostridium Difficile Infection

Antibiotic-associated diarrhea and colitis resulting from *C difficile* infection can complicate the course of treatment for many patients. The antimicrobials most commonly involved include clindamycin, penicillins, cephalosporins, and quinolones, although *C difficile* has been described in association with almost all antimicrobials. Patients do not need to receive antimicrobial therapy to develop this condition.

C difficile is also recognized as an important nosocomial pathogen capable of cross transmission to patients in adjacent areas. Diagnosis is usually based on identification of *C difficile* toxins and detection of cytotoxin activity in tissue culture. Toxin testing is hampered by lack of sensitivity, and the polymerase chain reaction testing appears to be rapid, sensitive and specific, and ultimately addresses testing errors.

Treatment begins with discontinuation of the implicated antimicrobial therapy (if possible) and initiation of specific antimicrobial therapy against *C difficile* if symptoms are moderate, severe, or persistent. The preferred regimen is oral metronidazole, 500 mg three times daily for 10 to 14 days. Oral vancomycin, 125 mg four times daily for 10 to 14 days, is also effective, and is the preferred therapy for severe infections. For patients who are unable to take oral medications, intraluminal vancomycin with or without intravenous metronidazole is recommended. Fidaxomicin is a first-in-class, narrow-spectrum macrocyclic antibiotic that acts by eradicating *C difficile* with minimal disruption of the normal intestinal flora. It is used when the vancomycin option fails. Fulminant colitis unresponsive to these measures or progressing to toxic megacolon may require total colectomy.



K. Fungal diseases

Life-threatening infections caused by fungi may be extremely difficult to diagnose by routine physical examination or routine cultures. *Candida albicans* is the most common etiologic organism in critically ill patients. Non-albicans species of *Candida* and other fungi have increased significantly in recent years. Fungal infection should be considered in certain geographic regions and in the presence of predisposing factors, such as HIV, malignancy, neutropenia, long-term use of steroids, broad-spectrum antimicrobial

therapy, parenteral nutrition, severe burns or organ transplantation, or central venous vascular catheters.

The polyenes (amphotericin B and lipid preparations of amphotericin B) have been the most commonly utilized antifungal agents for serious infections. Newer agents (caspofungin, voriconazole) have shown comparable or superior clinical outcomes compared with the polyenes and have much less toxicity than usually associated with amphotericin B. All lipid formulations have less nephrotoxicity, and their efficacy against *Candida* is equivalent to conventional amphotericin B. Fluconazole is still active against most *Candida* species and *Cryptococcus*, and itraconazole may be used for some of the mold infections. Both agents have an important role in primary or secondary prophylaxis. The newer agents, such as voriconazole, posaconazole, and caspofungin, have activity against resistant *Candida* strains and some of the mold infections resistant to other regimens. Voriconazole is the drug of choice for *Aspergillus* infection.

L. Other therapy

In addition to antimicrobial therapy, surgical intervention must be considered in patients with life-threatening infections. Any abscess must be drained, and injured or ischemic organs must be repaired or removed. Vascular catheters that may be a source of infection should be removed.

Early surgical consultation should be sought when the abdomen may be a source of infection in the critically ill patient. Guidelines for tetanus prophylaxis are found in **Chapter 9**. Further management of the patient with septic shock is discussed in **Chapter 7**.

M. Healthcare-associated infection control

Patients can acquire healthcare-associated infections (HAIs) during the course of receiving treatment for other conditions within a healthcare setting. For example, pneumonia would meet the healthcare-associated criteria if the patient was hospitalized for at least 2 of the preceding 90 days, was a resident in a nursing home or extended-care facility, received home intravenous (antibiotics or chemotherapy) therapy, or received chronic dialysis or home wound care (or both) during the preceding 30 days.

Recent data estimate that one of every 25 hospitalized patients experience a HAI each year. Pneumonia and surgical site infection from any inpatient surgery were the most common HAIs. Many studies show that HAI increases hospital length of stay and

morbidity and mortality rates. Strategies have been proposed to prevent HAI. More details are available in the Web sites listed at the conclusion of this chapter. Guidelines cannot always account for variations among patients and are not intended to supplant physician judgment with respect to individual patients or special clinical situations.

Key Points

Life-Threatening Infections

- Fever is the most frequent systemic manifestation that raises the suspicion of infection.
- Ideally, appropriate cultures should be obtained before initiation of antibiotics in patients with suspected infection.
- Selection of appropriate empiric antimicrobial therapy depends on the suspected pathogen(s) and site of infection, Gram stain results of available specimens from the suspected site, assessment for antimicrobial resistance, and comorbid conditions.
- When bacterial meningitis is suspected clinically, antimicrobial therapy should be instituted immediately, without waiting for the results of lumbar puncture.
- The most common organism resulting in community-acquired, life-threatening pneumonia is *Streptococcus pneumoniae*.
- Resistant gram-negative organisms and *Staphylococcus aureus* are frequent causes of pneumonia in hospitalized patients or in those who require mechanical ventilation.
- Bactericidal antimicrobial therapy, high concentrations of the antimicrobial agent, the resistance pattern of the microorganism, and long-term therapy are the cornerstones of therapy for infective endocarditis.
- Suspicion of intra-abdominal infection requires the prompt involvement of a surgeon.
- Necrotizing soft tissue infection requires prompt surgical debridement in addition to broad-spectrum antimicrobial therapy.

- In the absence of a specific source and pending culture results, broad-spectrum antimicrobial therapy is indicated in the immunocompromised or neutropenic patient with fever.
- Fungal infection should be considered in the presence of predisposing factors, such as malignancy, neutropenia, broad-spectrum antimicrobial therapy, parenteral nutrition, severe burns, or organ transplantation, or if central venous vascular catheters are in place.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. O'Grady NP, Barie PS, Bartlett JG, et al. Guidelines for evaluation of new fever in critically ill adult patients: 2008 update from the American College of Critical Care Medicine and the Infectious Diseases Society of America. *Crit Care Med*. 2008;36:1330-1349.
2. American Thoracic Society, Infectious Diseases Society of America. Guidelines for the management of hospital-acquired, ventilator-associated, and healthcare-associated pneumonia. *Am J Respir Crit Care Med*. 2005;171:388-416.11
3. Avecillas JF, Mazzone P, Arroliga AC. A rational approach to the evaluation and treatment of the infected patient in the intensive care unit. *Clin Chest Med*. 2003;24:645-669.
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12. Pappas PG, Kaufman C, Andes D, et al. Clinical practice guidelines for the management of candidiasis: 2009 update by the Infectious Diseases Society of America. *Clin Infect Dis*. 2009;48:503-535.

13. Solomkin JS, Mazuski JE, Bradley J, et al. Diagnosis and management of intra-abdominal infection in adults and children: Guidelines by the Surgical Infection Society and the Infectious Diseases Society of America. *Clin Infect Dis*. 2010;50:133-164.

14. Tunkel AR, Hartman BJ, Kaplan SL, et al. Practice guidelines for the management of bacterial meningitis. *Clin Infect Dis*. 2004;39:1267-1284.

15. Yokoe DS, Anderson DJ, Berenholtz SM, et al. A compendium of strategies to prevent healthcare-associated infections in acute care hospitals: 2014 update. *Infect Control Hosp Epidemiol*. 2014;35:455-459.

Suggested Websites

1. Society of Critical Care Medicine. http://sccm.org.

2. Centers for Disease Control. http://www.cdc.gov.

3. Infectious Diseases Society of America. http://www.idsociety.org.

MANAGEMENT OF LIFE-THREATENING ELECTROLYTE AND METABOLIC DISTURBANCES

Objectives

- Review the emergent management of severe electrolyte disturbances.
- Recognize manifestations of acute adrenal insufficiency and initiate appropriate treatment.
- Describe the management of severe hyperglycemic syndromes.

Case Study

A 78-year-old woman with diabetes mellitus, heart failure, and chronic renal insufficiency is admitted to the hospital with altered mental status. She has continued to take her home medications, including furosemide and metformin. According to her family, she has had a decreased appetite over the past week and increasing lethargy. Her vital signs are as follows: blood pressure 98/52 mm Hg, heart rate 110 beats/min, respiratory rate 18 breaths/min, and temperature 36.4°C (97.6°F). The electrocardiography monitor shows frequent premature ventricular contractions.

– What risk factors does this patient have for electrolyte disturbances?

– Which electrolyte abnormalities might contribute to her presentation?

– How would you initiate the evaluation and treatment of this patient?

I. INTRODUCTION

Electrolyte and metabolic disturbances are common in critically ill and injured patients. These abnormalities alter physiologic function and contribute to morbidity and

mortality. The most common life-threatening electrolyte and metabolic disorders in critically ill patients are disturbances in potassium, sodium, calcium, magnesium, phosphate, and glucose levels. With early recognition and treatment of these abnormalities, potentially life-threatening complications may be avoided and outcomes improved.

II. ELECTROLYTE DISTURBANCES

Electrolyte disturbances result from an underlying disease process. It is important to seek the cause of the abnormality, as well as to treat the electrolyte change itself. Many clinical manifestations are not specific to a particular electrolyte change and may be due to multiple abnormalities. The urgency of treatment depends on the clinical circumstances rather than the absolute electrolyte concentration. All severe electrolyte abnormalities require frequent reassessment during correction.

A. Potassium

Potassium is primarily an intracellular ion that is essential for maintenance of the electrical membrane potential. Approximately 2% of total body potassium is present in the extracellular compartment. Alterations in this ion primarily affect the cardiovascular, neuromuscular, and gastrointestinal systems.

1. Hypokalemia

Hypokalemia (potassium <3.5 mmol/L) results from renal or extrarenal losses, transcellular shifts, and decreased intake (**Table 12-1**). Life-threatening clinical manifestations of hypokalemia primarily involve the cardiac and neuromuscular systems. Dysrhythmias (ventricular and supraventricular, conduction delays, sinus bradycardia), electrocardiogram (ECG) abnormalities (U waves, QT-interval prolongation, flat or inverted T waves), muscle weakness or paralysis, paresthesias, ileus, abdominal cramps, nausea, and vomiting are common manifestations.

Table 12-1	Causes of Hypokalemia		
Transcellular Shifts	**Renal Losses**	**Extrarenal Losses**	**Decreased Intake**
Acute alkalosis	Diuresis	Diarrhea	Malnutrition
Hyperventilation	Metabolic alkalosis	Profuse sweating	Alcoholism
Insulin	Renal tubular defects	Nasogastric suction	Anorexia nervosa

β-Adrenergic agonists	Diabetic ketoacidosis
	Drugs (diuretics, aminoglycosides, amphotericin B)
	Hypomagnesemia
	Vomiting
	Hyperaldosteronism
	Cushing syndrome

Treatment of hypokalemia is aimed at correcting the underlying cause and administering potassium (**Figure 12-1**). Discontinue offending drugs (if possible), correct hypomagnesemia and other electrolyte disturbances, and correct alkalosis. Because potassium is primarily an intracellular ion, an estimated deficit cannot be calculated from serum values. Therefore, administration must be titrated against periodic reassessment of the serum levels. Infusion of 20 mmol potassium in 100 mL fluid over 1 hour, with additional doses administered sequentially, is recommended to avoid potential complications with more concentrated solutions. This concentration must be administered through a central line, although more dilute solutions can be administered peripherally. The infusion rate can be slowed after life-threatening symptoms resolve. Serum potassium levels must be monitored at frequent intervals during repletion (ie, every 3-4 hours during initial replacement). If acidemia is present, correct the potassium level before correcting the pH, since potassium shifts intracellularly as the pH increases.

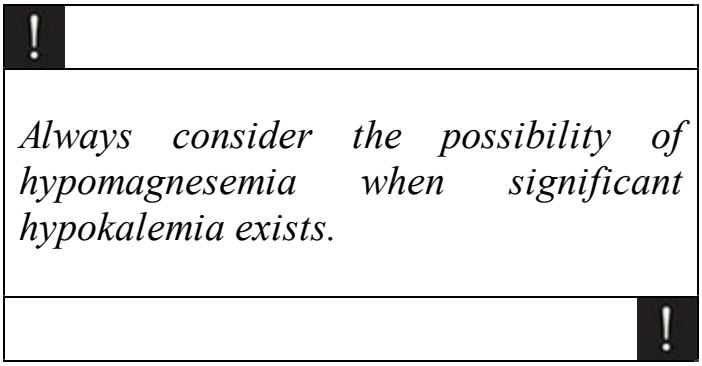
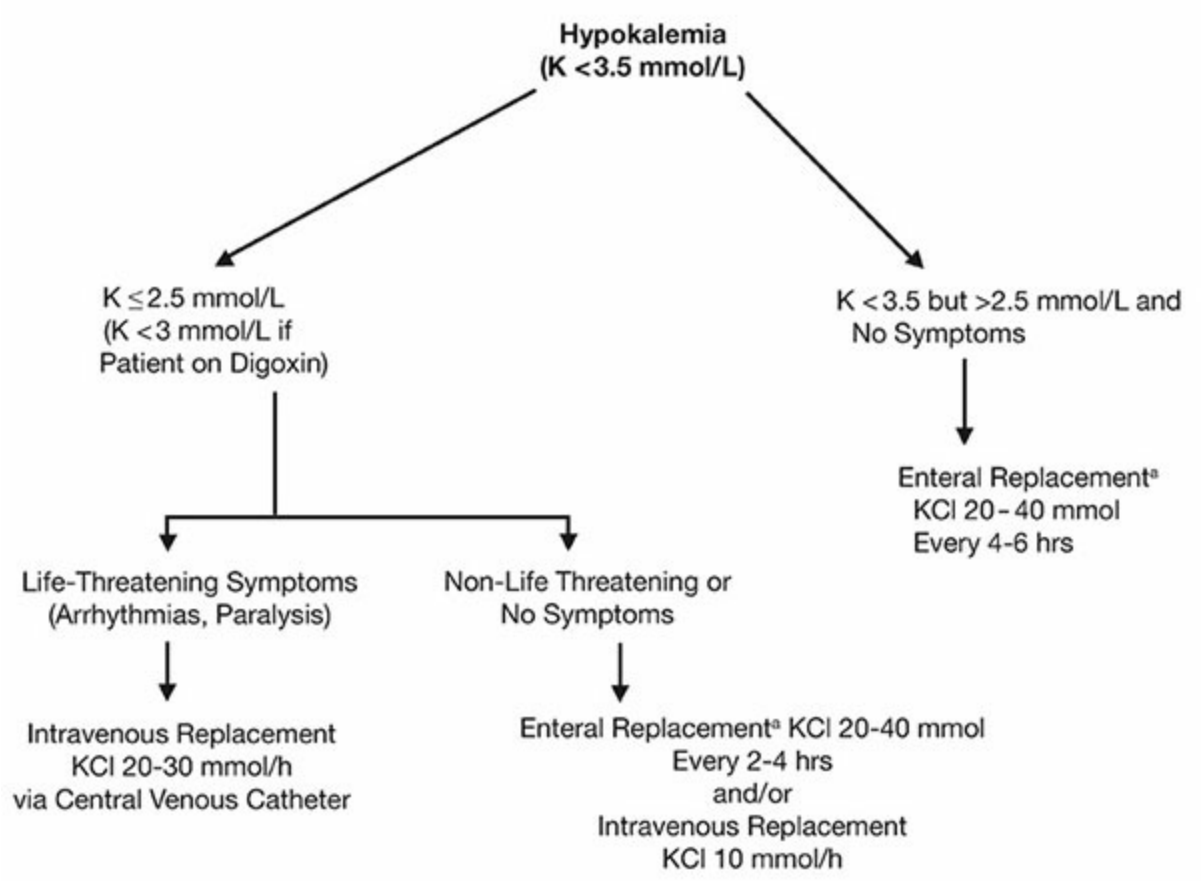


Figure 12-1. Treatment of Hypokalemia



2. Hyperkalemia

Hyperkalemia (potassium >5.5 mmol/L) in critically ill patients most often results from renal dysfunction. Other causes are listed in **Table 12-2**. Pseudohyperkalemia may result from a white blood cell count >100,000/mm^3 or platelet count >600,000/mm^3. Hemolysis secondary to phlebotomy technique must also be considered.

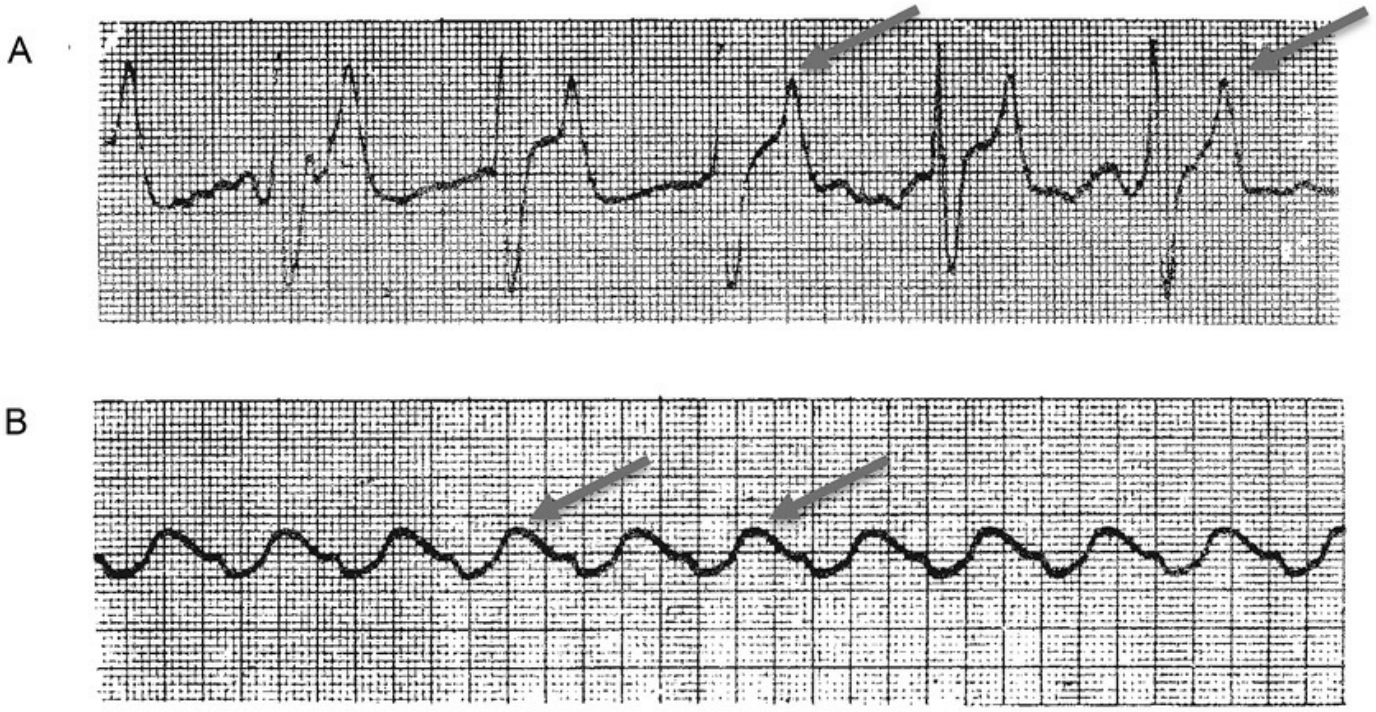
Table 12-2 Causes of Hyperkalemia

- Renal dysfunction
- Acidemia
- Hypoaldosteronism
- Drugs (eg, potassium-sparing diuretics, angiotensin-converting enzyme inhibitors, succinylcholine, nonsteroidal anti-inflammatory drugs, trimethoprim-sulfamethoxazole)
- Cell death
  - Rhabdomyolysis
  - Tumor lysis
  - Burns
  - Hemolysis
- Excessive intake

Clinical manifestations of hyperkalemia relate primarily to the heart and muscle (**Figure 12-2**). Arrhythmias, heart block, bradycardia, diminished conduction and contraction,

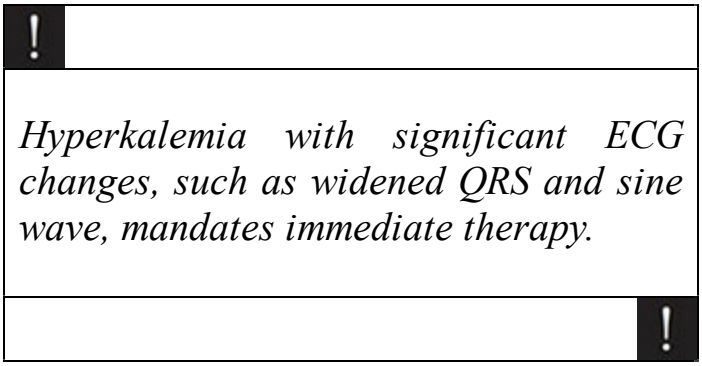
ECG abnormalities (eg, diffuse peaked T waves, PR interval prolongation, QRS widening, diminished P waves, sine waves), muscle weakness, paralysis, paresthesias, and hypoactive reflexes are common manifestations.

Figure 12-2. Electrocardiographic Effects of Hyperkalemia



Two rhythm strips showing the electrocardiographic effects of hyperkalemia. **A**, peaked T waves and widened QRS complex. **B**, sine wave pattern.

Treatment of hyperkalemia involves the recognition and treatment of underlying diseases, the removal of offending drugs, the limitation of potassium intake, and the correction of acidemia or electrolyte abnormalities. Any serum potassium level >6 mmol/L should be addressed, but the urgency of treatment depends on the clinical manifestations and ECG findings. Options for treating hyperkalemia are summarized in **Table 12-3**. Serum potassium levels, continuous cardiac monitoring, and serial ECG tracings should be obtained during evaluation and treatment.



Hyperkalemia with significant ECG changes, such as widened QRS and sine wave, mandates immediate therapy.

Table 12-3	Options for Treating Hyperkalemia

If Significant Electrocardiographic Abnormalities Are Present

Administer calcium chloride, 5-10 mL of a 10% solution, intravenously over 5-10 minutes to stabilize the myocardial cell membrane and decrease the potential for arrhythmias. If calcium gluconate is used, 10-20 mL of a 10% solution is needed for treatment because of the lower elemental calcium content. The effect lasts only 30-60 minutes and should be followed by additional treatment.

For Redistribution of Potassium

1. Administer insulin and glucose (10 units of regular insulin with 50 g of 50% dextrose over 5-10 minutes intravenously). Glucose monitoring is necessary to avoid hypoglycemia.
2. Administer sodium bicarbonate (1 mmol/kg intravenously over 5-10 minutes). Be aware of the potential for sodium overload. Sodium bicarbonate is less effective than glucose and insulin for decreasing the potassium level in patients with end-stage renal failure.
3. Administer inhaled β_2-agonists in high doses (albuterol [salbutamol], 10-20 mg), which can decrease serum potassium by approximately 0.5 mmol/L.

For Removal of Potassium From the Body

1. Increase urine output with a loop diuretic (furosemide, 1-2 mg/kg) and isotonic fluids.
2. Increase gastrointestinal potassium loss with sodium polystyrene, 25-50 g in sorbitol, enterally or by enema. (Be aware of potential for sodium overload. This may not be a good option in critical illness.)
3. Initiate dialysis.

B. Sodium

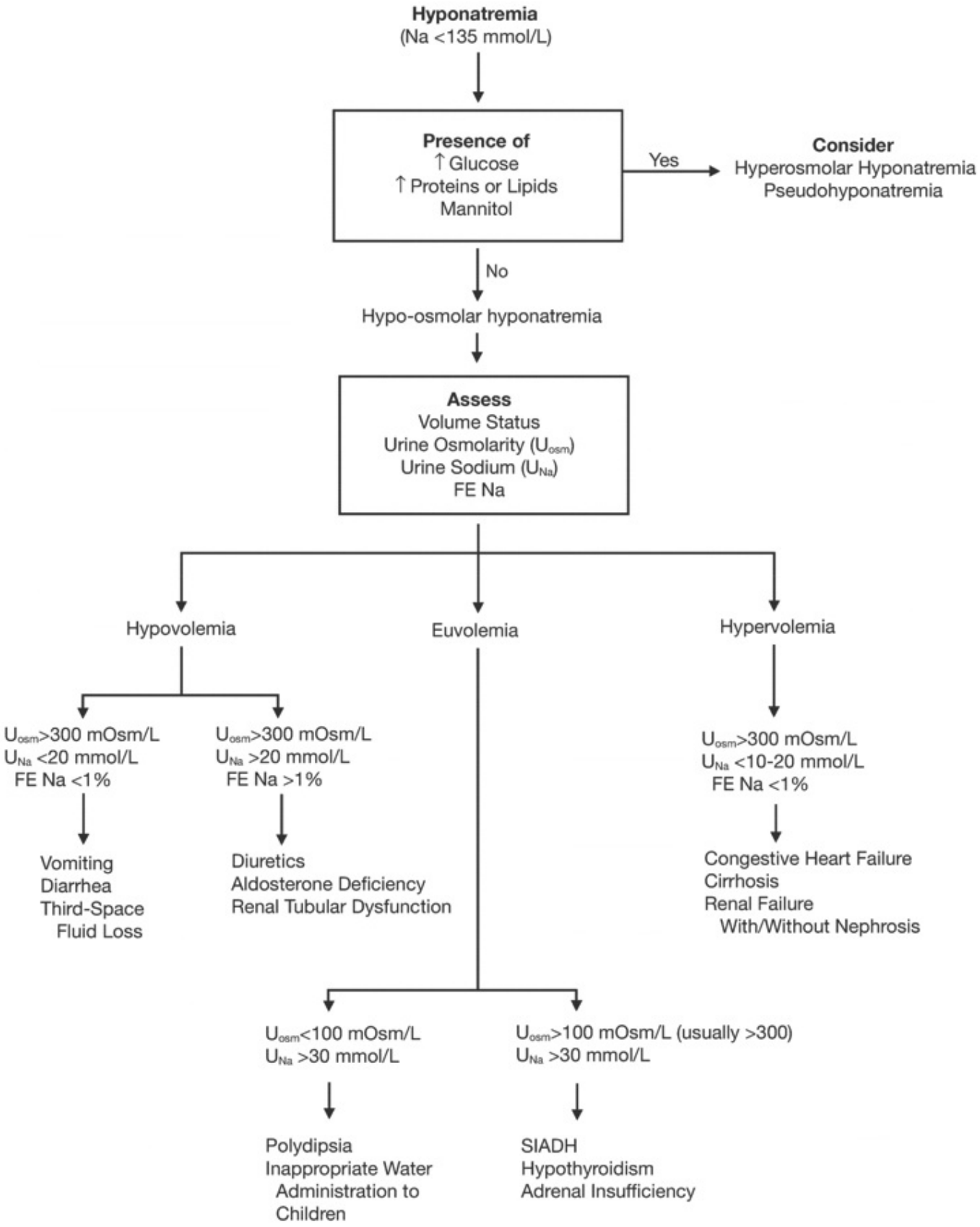
Sodium functions as the primary determinant of blood osmolality and is involved in the regulation of extracellular volume. Abnormalities in circulating sodium primarily affect neuronal and neuromuscular function.

1. Hyponatremia

Understanding the cause of hyponatremia starts by assessing the patient's intravascular volume status. The most common cause of hyponatremia (sodium <135 mmol/L) associated with a low serum osmolality (hypo-osmolar hyponatremia) is excess secretion of antidiuretic hormone (ADH) (ie, euvolemic hyponatremia). Hypo-osmolar hyponatremia or dilutional hyponatremia can also be associated with hypovolemic or hypervolemic conditions. A common defect is impaired ability to excrete free water through the kidneys. Less frequently, hyponatremia can result from the presence of a nonsodium solute, such as glucose and mannitol. These causes are characterized by a normal or elevated serum osmolality. Pseudohyponatremia, a spurious form of iso-osmolar hyponatremia, may occur in the presence of severe hyperlipidemia,

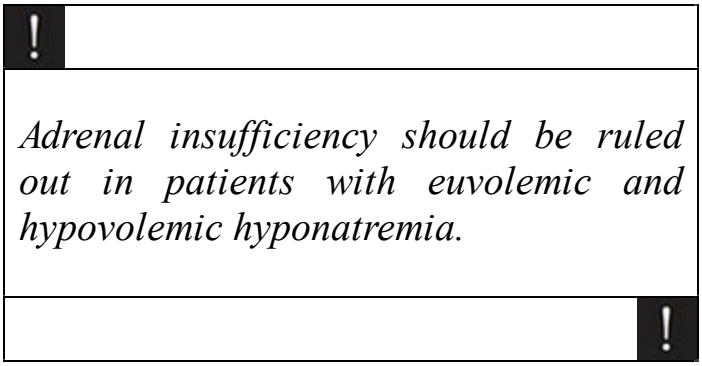
hyperproteinemia, or hyperglycemia when the sodium concentration is measured by flame photometry. **Figure 12-3** outlines a diagnostic approach to determining the etiology of hyponatremia.

Figure 12-3. Diagnostic Approach to the Etiology of Hyponatremia



Abbreviations: FE Na, fractional excretion of sodium; SIADH, syndrome of inappropriate antidiuretic hormone

Clinical manifestations of hyponatremia involve the central nervous system (CNS) and muscular system and include disorientation, decreased mentation, irritability, seizures, lethargy, coma, nausea/vomiting, weakness, and respiratory arrest. Treatment requires identifying the type of hyponatremia, treating the underlying disease, removing offending drugs, and improving the circulating sodium level. Hypovolemic hyponatremia usually responds to intravascular volume repletion (ie, with normal saline). As volume is replaced, the release of ADH is appropriately suppressed and the kidneys begin to excrete free water. Hypervolemic hyponatremia is usually not severe and improves with successful treatment of the underlying condition.



Euvolemic hyponatremia is almost always secondary to elevated levels of ADH. Diagnosis is facilitated by determining urine osmolality before treatment (especially with diuretics) to compare with a calculated serum osmolality [(2 × serum sodium) + glucose/18 + blood urea nitrogen/2.8]. The urine osmolality is inappropriately higher than serum osmolality (usually >300 mOsm) in the syndrome of inappropriate ADH (SIADH). If the hyponatremia is acute or the patient is symptomatic, the serum sodium level should be increased by restricting free-water intake, increasing free-water clearance with loop diuretics, and replacing intravascular volume with normal saline (154 mmol/L) or hypertonic 3% saline (513 mmol/L). Hypertonic saline is indicated for treatment in the presence of severe symptoms, such as seizures, coma, or impending respiratory arrest. The goal of therapy in this situation is to remove free water and not sodium. The increase in serum sodium should be controlled, and although the precise rate of increase is controversial, the serum sodium increase should be limited to approximately 6 to 8 mmol/L in the first 24 hours. One option is to accelerate the rate of serum sodium elevation early in the treatment course in the presence of life-threatening symptoms, such as seizures, and then slow the rate of increase after resolution of the symptoms. When hypertonic saline is used in symptomatic patients, 1 mmol/kg sodium chloride should be infused initially (3% saline contains ~0.5 mmol/mL). The same amount can be administered in incremental doses to a maximum of 3 to 5 mmol/kg or until symptoms resolve. Alternatively, the change in serum sodium expected after administering 1 liter of fluid can be estimated by using the following formulas:

$$\text{Change in Serum Sodium} = \frac{\text{Infusate Sodium} - \text{Serum Sodium}}{\text{Total Body Water} + 1}$$

$$\text{Change in Serum Sodium} = \frac{(\text{Infusate Sodium} + \text{Infusate Potassium}) - \text{Serum Sodium}}{\text{Total Body Water} + 1}$$

Total Body Water = 0.6 × Weight (kg) for men; 0.5 × Weight (kg) for women

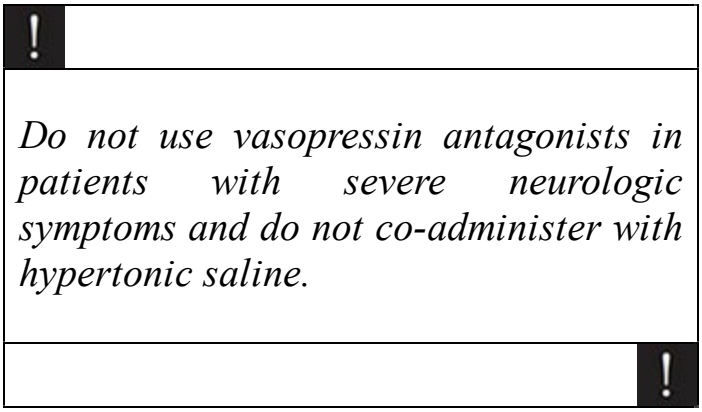
The sodium concentrations of various infusates are listed in **Table 12-4**. The formulas presented above do not take into account other fluid gains and losses (ie, urine output), and therefore, should serve only as guides to intervention. Serum sodium levels should be monitored at frequent intervals during therapy for hyponatremia. When serum sodium is greater than 125 to 130 mmol/L, restriction of free water alone allows for slower return of the sodium level to normal. Correction of the serum sodium level that is too rapid may result in CNS injury (ie, osmotic demyelinating syndrome), particularly in the setting of chronic hyponatremia. Osmotic demyelinating syndrome rarely occurs in patients whose serum sodium is greater than 120 mmol/L. Symptoms of demyelination are typically seen after initial improvement in mentation. In 1 to 7 days following a hasty reversal of chronic hyponatremia, patients may develop focal motor deficits, respiratory insufficiency, and progressive loss of consciousness. Patients at greatest risk for osmotic demyelinating syndromes are those with malnutrition or hypokalemia, alcohol abusers, elderly women, and burn patients. If hyponatremia is chronic and the patient is asymptomatic, regardless of the magnitude of hyponatremia, free-water restriction alone may be sufficient to allow for slow return of serum sodium to normal.

Table 12-4 Sodium Characteristics of Selected Infusates

Infusate	Sodium Concentration (mmol/L)
5% sodium chloride	855
3% sodium chloride	513
0.9% sodium chloride	154
Ringer lactate solution	130
0.45% sodium chloride	77
5% dextrose in water	0

Although controversial, vasopressin receptor antagonists, such as conivaptan and tolvaptan, are available for use in the management of hyponatremia. These agents should not be used in the management of acute hyponatremia and expert consultation should be sought before their use. They inhibit resorption of water via their action on the V2 receptor of the kidney and result in a slow rise in the serum sodium level. Alternative

therapy, such as hypertonic saline, should be given to patients with severe hyponatremia complicated by neurologic symptoms due to the need to initially rapidly correct the sodium level. Vasopressin receptor antagonists can cause hypotension and volume depletion and therefore should be avoided in patients with hypovolemia. After a vasopressin receptor antagonist is administered, serum sodium levels should be monitored frequently (every 4 hours) due to concerns for rapid sodium correction and neurological sequelae (specifically, demyelination). To prevent over-correction, avoid using vasopressin antagonists in combination with hypertonic saline. Once an increase of 6 to 8 mmol/L is achieved, consider replacing free water (orally or intravenously) to match urine output and prevent an excessive rise in sodium levels.



2. Hypernatremia

Hypernatremia (sodium >145 mmol/L) indicates intracellular volume depletion with a loss of free water that exceeds sodium loss. Causes of hypernatremia are listed in **Table 12-5**.

Table 12-5 Causes of Hypernatremia

Water Loss	Reduced Water Intake	Excessive Sodium Intake
Diarrhea	Altered thirst	Salt tablets
Vomiting	Impaired access	Hypertonic saline
Excessive sweating		Sodium bicarbonate
Diuresis		
Diabetes insipidus		

The clinical manifestations of hypernatremia relate to CNS and muscle function. Manifestations of hypernatremia include altered mentation, lethargy, seizures, coma, and muscle weakness. Polyuria suggests the presence of diabetes insipidus or excess salt

and water intake.

Treatment focuses on correcting the underlying cause of hypernatremia. Nearly all patients with hypernatremia require free-water repletion. The water deficit can be estimated by using the following equation:

Water Deficit (L) = 0.6 (0.5 for women) × weight (kg) [(measured Na/normal Na) – 1]

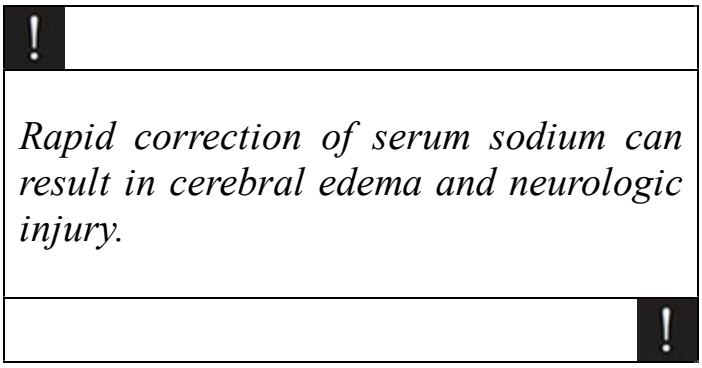
Example: Water deficit of a 70-kg man with sodium measurement of 160 mmol/L
0.6 × 70 [(160/140) – 1]
42 [1.14 – 1]
42 × 0.14 = 5.88 L water deficit

A portion of free water should be replaced initially at a speed commensurate with the severity of symptoms, and the patient should be reevaluated for subsequent replacement. Regardless of the serum sodium level, if the patient shows signs of hypovolemic shock (eg, hypotensive, orthostatic, or significantly tachycardic), administer normal saline until the intravascular volume is corrected. When the patient is hemodynamically stable, replete the remaining water deficit with 5% dextrose in water, 0.45% NaCl, or 0.2% NaCl with 5% dextrose. To estimate the change in serum sodium expected after administering 1 liter of fluid, use the same formulas as for hyponatremia:

$$\text{Change in Serum Sodium} = \frac{\text{Infusate Sodium} - \text{Serum Sodium}}{\text{Total Body Water} + 1}$$

$$\text{Change in Serum Sodium} = \frac{(\text{Infusate Sodium} + \text{Infusate Potassium}) - \text{Serum Sodium}}{\text{Total Body Water} + 1}$$

In stable patients, water may be replaced via the enteral route (ie, nasogastric tube). In the rare patient with extreme sodium overload, sodium may be removed with loop diuretics or dialysis (provided intravascular volume is adequate). Administration of aqueous vasopressin or desmopressin should be considered for patients with central diabetes insipidus.



Sodium concentrations should be measured frequently during treatment, and therapy should be adjusted for optimal correction of the sodium level. If hypernatremia developed over a period of hours, reducing the serum sodium by 1 mmol/L/h is appropriate. In hypernatremia of longer or unknown duration, a slower rate of correction (0.5 mmol/L/h) is recommended. Increasing free-water intake in maintenance fluids allows for a slow return to normal sodium levels.

C. OTHER ELECTROLYTE ABNORMALITIES

1. Calcium

Calcium is required for muscle contraction, nerve impulse transmission, hormone secretion, blood clotting, cell division, cell motility, and wound healing. Effective calcium levels in a seriously ill patient are best assessed by using ionized calcium measurements, if available. If treatment decisions are based on total serum calcium, the albumin concentration must be considered as 40% of circulating calcium is protein bound, mainly to albumin. In general, for each increase or decrease in serum albumin of 1 g/dL, the serum calcium increases or decreases by 0.8 mg/dL (0.2 mmol/L). However, the relationship between albumin and serum calcium is less reliable in critically ill patients.

a. Hypocalcemia

Hypocalcemia (total calcium <8.5 mg/dL [<2.12 mmol/L], ionized calcium <1 mmol/L) is common in critically ill patients and results from impairment of the parathyroid and/or vitamin D systems (**Table 12-6**). Cardiovascular abnormalities, the most common clinical manifestations of hypocalcemia in critically ill patients, include hypotension, bradycardia, arrhythmias, heart failure, cardiac arrest, digitalis insensitivity, and QT-interval and ST-segment prolongation. Neuromuscular manifestations include weakness, muscle spasm, laryngospasm, hyperreflexia, seizures, tetany, and paresthesias.

Table 12-6	Causes of Hypocalcemia	
Hypoparathyroidism	Pancreatitis	Calcium chelators
Sepsis	Malabsorption	Hypomagnesemia
Burns	Liver disease	Massive transfusion
Rhabdomyolysis	Renal disease	

Treatment is aimed at correcting the underlying disease process and any concomitant

electrolyte abnormalities, and administering calcium. Mild hypocalcemia is well tolerated, and aggressive treatment may result in tissue injury (especially during ischemic and septic states). If the hypocalcemia is severe or if the patient is symptomatic, administer 100 mg calcium intravenously over 5 to 10 minutes (3-4 mL of 10% calcium chloride or 10 mL of 10% calcium gluconate), followed by calcium in the amount of 0.3 to 2 mg/kg/h. Calcium preparations vary in their content of elemental calcium: 1 g of 10% calcium *chloride* contained in 10 mL has 272 mg of calcium; 1 g of 10% calcium *gluconate* contained in 10 mL has 90 mg of calcium. When the circulating calcium concentration is stable, calcium may be replaced via the enteral route (ie, 500-1,000 mg every 6 hours).

Monitor ionized or total calcium levels frequently during treatment, and adjust repletion to maintain calcium in the lower normal range so as not to suppress parathyroid gland function. If calcium replacement alone fails to maintain the circulating calcium level, consider administration of vitamin D and confirm normal magnesium levels. Adverse effects of calcium administration include hypercalcemia, bradycardia, nausea/vomiting, flushing, and tissue calcium precipitation.

b. Hypercalcemia

The most common causes of hypercalcemia (total calcium >11 mg/dL [>2.75 mmol/L], ionized calcium >1.3 mmol/L) are the result of calcium release from bone (**Table 12-7**). The clinical manifestations of hypercalcemia relate primarily to the cardiovascular and neuromuscular systems and include hypertension, cardiac ischemia, arrhythmias, bradycardia, conduction abnormalities, digitalis toxicity, dehydration, hypotension, weakness, depressed mentation, coma, seizures, and sudden death. Gastrointestinal manifestations include nausea/vomiting, anorexia, abdominal pain, constipation, pancreatitis, and ulcer disease. Nephrogenic diabetes insipidus with polyuria may occur and contribute to volume depletion. Renal stones, nephrocalcinosis, and renal failure may also be encountered.

Table 12-7	Causes of Hypercalcemia
Hyperparathyroidism	Excess intake of vitamin A or vitamin D
Malignancy	Thyrotoxicosis
Immobilization	Granulomatous disease

Treatment of hypercalcemia is aimed at controlling the underlying disease, rehydrating the patient, and lowering the calcium level. The circulating calcium level frequently needs to be lowered while the primary disease is being evaluated and treated. Intravascular volume should be restored with normal saline to ensure adequate tissue

perfusion and renal blood flow (urine output 2-3 mL/kg/h). Saline also decreases renal tubular calcium reabsorption. Once adequate volume status is secured, diuresis with a loop diuretic further increases calcium excretion. Serum potassium and magnesium levels should be monitored and low levels corrected. In patients with renal failure, pulmonary edema, or life-threatening hypercalcemia, calcium levels may be lowered with dialysis. After initial stabilization, therapy with calcitonin and bisphosphonates can be considered.

2. Phosphorus

Phosphate is important in cellular energy metabolism. Hypophosphatemia (phosphate <2.5 mg/dL [0.81 mmol/L]) results from transcellular shifts, renal loss, gastrointestinal loss, or inadequate intake (**Table 12-8**). Phosphate depletion primarily affects the neuromuscular and central nervous systems. Clinical manifestations include muscle weakness, respiratory failure, rhabdomyolysis, paresthesias, lethargy, disorientation, obtundation, coma, and seizures. Other possible complications include impaired renal tubular function, impaired pressor response, hepatic dysfunction, immune dysfunction, impaired protein synthesis, hemolysis, impaired platelet function, and impaired oxygen off-loading from hemoglobin.

Table 12-8 Causes of Hypophosphatemia

Transcellular Shift	Renal Loss	Gastrointestinal Loss	Decreased Intake
Acute alkalosis	Hyperparathyroidism	Malabsorption	Malnutrition
Carbohydrate administration	Diuretic use	Diarrhea	Parenteral nutrition
Drugs (insulin, epinephrine)	Hypokalemia	Intestinal fistulas	
	Hypomagnesemia	Antacids	
	Steroids		

Treatment of hypophosphatemia consists of controlling the underlying disease, removing offending drugs, correcting electrolyte abnormalities, and replacing phosphate. Phosphate levels <1 mg/dL (<0.32 mmol/L) associated with symptoms are considered life-threatening and require immediate treatment. For emergency treatment, administer phosphate at 0.6 to 0.9 mg/kg daily intravenously. When circulating levels are stable, maintenance replacement of phosphate is 1,000 mg/day intravenously plus excess estimated losses (ie, in urine or stool). Phosphate may be administered as potassium phosphate (93 mg/mL phosphate, 1.1 mmol/mL potassium) or sodium phosphate (93 mg/mL). Enteral administration of phosphate is preferred in patients with serum phosphate levels >1.0 to 1.5 mg/dL (>0.32-0.48 mmol/L).

Serum phosphate should be monitored during repletion and therapy adjusted to achieve

a circulating level of 3 to 4 mg/dL (0.97-1.29 mmol/L). Adverse effects of phosphate administration include hyperphosphatemia, hypocalcemia, tissue calcium precipitation, renal injury, and diarrhea (enteral phosphate).

Hyperphosphatemia is uncommon in critical illness except with renal failure. Increased bone metabolism secondary to tumors or increased gut absorption also may cause hyperphosphatemia. Symptoms are similar to those of hypocalcemia: ventricular arrhythmias, prolonged QT interval, seizures, paresthesias, and muscle cramps. Hyperphosphatemia is treated with intravenous calcium and enteral phosphorus binders. Dialysis may be initiated with renal failure.

3. Magnesium

Magnesium is important to the body for energy transfer and electrical stability. Causes of hypomagnesemia (magnesium <1.8 mg/dL or 1.5 mEq/dL [<0.75 mmol/L]) are listed in **Table 12-9**.

Table 12-9 Causes of Hypomagnesemia

Renal Loss	Gastrointestinal Loss	Transcellular Shift	Decreased Intake
Renal tubular dysfunction	Malabsorption	Refeeding	Malnutrition
Diuresis	Diarrhea	Recovery from	Alcoholism
Hypokalemia	Nasogastric suction	hypothermia	Parenteral nutrition
Drugs (eg, aminoglycosides, amphotericin)			

Clinical manifestations of hypomagnesemia overlap those of hypokalemia and hypocalcemia, including cardiovascular abnormalities (ie, QT-interval prolongation, arrhythmias, vasospasm, myocardial ischemia), neuromuscular abnormalities (eg, weakness, tremor, seizures, tetany, obtundation, coma), and electrolyte abnormalities (eg, hypokalemia, hypocalcemia).

Treatment of hypomagnesemia consists of addressing the underlying disease, discontinuing problematic drugs, correcting concomitant electrolyte abnormalities, and replenishing magnesium. For emergency treatment (ie, arrhythmias), administer 1 to 2 g magnesium sulfate intravenously over 5 to 10 minutes. The agent can be administered over a longer interval (10-60 minutes) in less-urgent situations. Depending on the clinical situation, subsequent intravenous replacement ranges from 1 to 2 g magnesium sulfate every 4 to 6 hours. Once serum levels stabilize, intravenous maintenance doses

are 0.1 to 0.2 mmol/kg daily (1 g magnesium sulfate = 8 mmol). Maintenance magnesium may be administered enterally. The dose should be reduced if renal failure is present. Magnesium levels should be monitored during repletion. Deep tendon reflexes can be used to assess for hypermagnesemia during replacement (ie, decreased at serum level 4-5 mg/dL [1.65-2.06 mmol/L]).

Hypermagnesemia is uncommon in critical illness but may be seen with renal failure or shifts in magnesium from intracellular fluid due to soft tissue injury as with crush, burn trauma, and rhabdomyolysis. Hyporeflexia, lethargy, and apnea may result. Treatment consists of administration of intravenous calcium, diuretic administration, and dialysis in severe cases.

III. METABOLIC DISTURBANCES

Case Study

A 21-year-old man presented to the emergency department with nonspecific complaints of a flu-like syndrome. He has a history of HIV but has not been taking his medications. His vital signs include respiratory rate 24 breaths/min, heart rate 132 beats/min, blood pressure 86/45 mm Hg, and temperature 39°C (102.2°F). His laboratory results are remarkable for a white blood cell count 3,400/mm^3. Blood cultures are obtained, and patient received broad-spectrum antibiotics as well as a 30 mL/kg intravenous fluid bolus. Due to persistent hypotension, he is started on 10 µg/min of norepinephrine, yet remains hypotensive.

– What metabolic disorders may contribute to the refractory hypotension?

– What testing is needed?

– What interventions should be considered?

A. Acute Adrenal Insufficiency

Acute adrenal insufficiency in the critically ill patient may result from preexisting or previously undiagnosed chronic disease of the adrenal glands or hypothalamic-pituitary axis, or acute conditions affecting these endocrine organs (**Table 12-10**). Patients with chronic disease may develop acute adrenal insufficiency precipitated by infection or

other stressors. In addition, functional impairment during serious illness may result from relative or absolute insufficiency of glucocorticoid production, which usually reverses with recovery from the illness. Relative adrenal insufficiency occurs when cortisol response is normal or high, but is reduced relative to the severity of illness.

Table 12-10	Etiologies of Adrenal Insufficiency

Chronic Conditions

Adrenal glands
- Autoimmune destruction
- Granulomatous disease (tuberculosis)
- HIV infection
- Other infection (cytomegalovirus, fungal)
- Primary or metastatic malignancy
- Drug effects (ie, ketoconazole)

Hypothalamic/pituitary axis
- Withdrawal from exogenous glucocorticoid therapy
- Hypopituitarism (tumors, infarction, radiation)
- Sarcoidosis, histiocytosis
- Head trauma

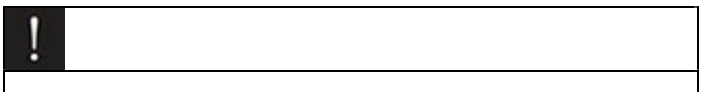
Acute Conditions

Critical illness (affects adrenal glands and hypothalamic-pituitary axis)
- Hypoperfusion
- Cytokine effects (altered cortisol metabolism, receptor affinity)

Acute adrenal hemorrhage
- Meningococcemia
- Disseminated intravascular coagulation
- Anticoagulation (eg, warfarin, heparin)

Drug effects
- Increased cortisol metabolism (phenytoin, phenobarbital, rifampin)
- Interference with glucocorticoid synthesis (ketoconazole, etomidate)

Lack of specific signs and symptoms of acute adrenal insufficiency makes for a challenging early diagnosis in the critically ill population. Clinical manifestations consistent with acute adrenal insufficiency include weakness, nausea and vomiting, abdominal pain, tachycardia, and orthostatic hypotension. A diagnostic clue is hypotension refractory to volume resuscitation. Suggestive laboratory findings may include eosinophilia, hyponatremia, hyperkalemia, acidosis, and hypoglycemia. Acute adrenal hemorrhage may cause abdominal, flank, or back pain. Clinical and laboratory manifestations overlap significantly with manifestations of other common critical illnesses, such as sepsis.



Electrolyte abnormalities are less likely with acute adrenal insufficiency compared to chronic adrenal insufficiency.

Important clues for possible adrenal insufficiency in seriously ill patients are vasopressor-dependent states and/or failure to respond to appropriate fluid administration, fever without apparent source, and a discrepancy between the expected disease severity and the patient's condition.

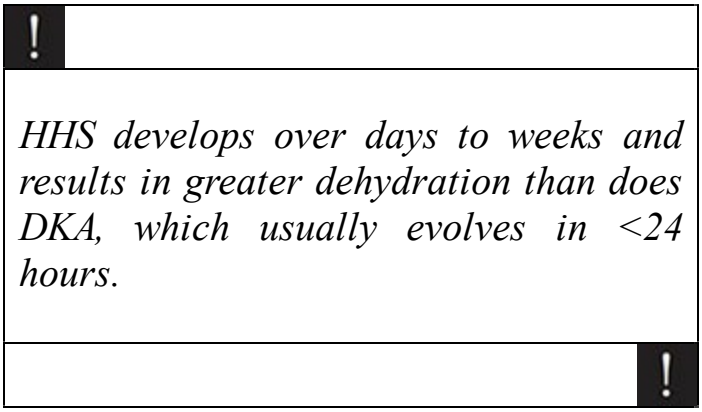
The value of standard tests for hypothalamic-pituitary-adrenal axis function using baseline cortisol levels and/or the short adrenocorticotropic hormone (ACTH) stimulation test is limited in the critically ill patient due to variation in testing methodology and lack of consensus criteria for absolute or relative adrenal insufficiency. Cortisol levels generally reflect total cortisol rather than metabolically active free cortisol. Thus, the decision to provide steroid therapy is made on clinical grounds. Current recommendations call for administration of 200 mg of hydrocortisone per day, in a continuous infusion or divided boluses for vasopressor-resistant septic shock. Improvement in hemodynamic status after administration of hydrocortisone may be an important physiologic indicator. Emergent treatment is indicated in critically ill patients, even if the diagnosis is not firmly established. Note that high-dose steroid therapy, previously employed in trials of shock management, has been deemphasized.

Hydrocortisone also provides some mineralo-corticoid effects.

If a clinical response to glucocorticoid (hydrocortisone) administration is observed and relative adrenal insufficiency is suspected, treatment should be continued until resolution of the critical illness. Steroids should be tapered when vasopressors are no longer required. Patients with evidence of persistent adrenal insufficiency (chronic or newly diagnosed) should be converted to oral steroid therapy. There is a limited role, if any, for steroid therapy in shock states other than anaphylaxis.

1. Diabetic Emergencies

Serious metabolic complications of diabetes result from a relative or absolute lack of insulin coupled with increased production of counter-regulatory hormones such as glucagon, catecholamines, cortisol, epinephrine, and others. Life-threatening hyperglycemic syndromes include diabetic ketoacidosis (DKA) and hyperglycemic hyperosmolar state (HHS). These syndromes differ in the severity of dehydration and degree of acidosis (ketosis) but share many clinical manifestations and therapeutic interventions. In addition, patients may manifest components of both syndromes. **Table 12-11** lists characteristics that may distinguish the syndromes, but considerable variability is possible. Although DKA and HHS may be the initial presentation of diabetes, the most common precipitating factors are infection and medication noncompliance. Other precipitants include corticosteroid use, myocardial infarction, stroke, alcohol abuse, pancreatitis, trauma, and pregnancy.



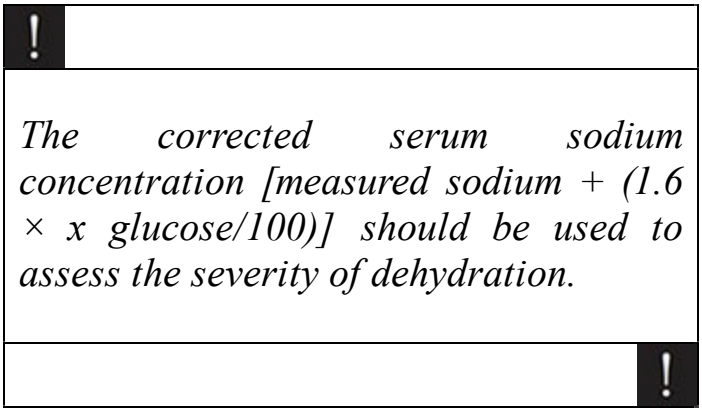
HHS develops over days to weeks and results in greater dehydration than does DKA, which usually evolves in <24 hours.

Table 12-11 Characteristics of Hyperglycemic Syndromes

	Diabetic Ketoacidosis	Hyperglycemic Hyperosmolar State
Glucose	>250 mg/dL	>600 mg/dL
Arterial/venous pH	<7.3	>7.3
Anion gap	Increased	Variable
Serum/urine ketones	Positive	Negative or small
Serum osmolality	Normal	Increased

Clinical manifestations result from hyperglycemia in both syndromes and from excess ketone production in DKA. Hyperglycemia causes hyperosmolality, osmotic diuresis, fluid and electrolyte loss, dehydration, and volume depletion. Ketones, specifically beta-hydroxybutyrate and acetate, are responsible for the metabolic acidosis and can be

measured indirectly by the anion gap. Clinical features of both hyperglycemic syndromes may include weakness, dehydration, polyuria, polydipsia, tachycardia, hypotension, anorexia, nausea/vomiting, and ileus. Abdominal pain, hyperpnea (Kussmaul respirations), and fruity odor to the breath are more characteristic of DKA, whereas altered mental status (ranging from lethargy to coma) and dysrhythmias are more common in HHS. Laboratory investigation may reveal hyperglycemia, hyperosmolality (more common in HHS), glucosuria, anion gap metabolic acidosis (DKA), hyperkalemia (when acidemia is present) or hypokalemia and hypophosphatemia (after insulin therapy is initiated), lactic acidosis, leukocytosis, and azotemia. Serum sodium concentrations may be low due to translocation of water to the extracellular space. An elevated serum sodium concentration suggests severe dehydration.



An initial rapid evaluation of the patient with a possible hyperglycemic condition should include assessment of mental status, degree of dehydration (vital signs, orthostatic changes, urine output), and presence of infection. Laboratory studies should include complete blood count, electrolytes, renal function, glucose (plasma or fingerstick), urine or serum ketones, and arterial blood gas (venous pH can be used as a substitute). An electrocardiogram should be obtained to evaluate for ischemia and changes due to electrolyte abnormalities. If infection is suspected, appropriate cultures are indicated.

The goals for treatment of hyperglycemic syndromes are to restore the fluid and electrolyte balance, provide insulin, and identify precipitating factors. The initial management of DKA and HHS is outlined in **Table 12-12**. Volume deficits correlate with the severity of hyperglycemia and are usually greater in HHS. Urine output should be maintained at 1 to 3 mL/kg/h to ensure adequate tissue perfusion and clearance of glucose.

Table 12-12	Initial Management of Hyperglycemic Syndromes

Fluids

1. Assess severity of dehydration.
2. Institute crystalloid resuscitation, initially with normal saline at approximately 15-20 mL/kg/h in the first hour in the absence of cardiac dysfunction to restore hemodynamic stability and renal perfusion. Subsequent fluid infusion rates should be guided by assessment of hydration and urine output, and 250-500 mL/h is often adequate.
3. After stabilization of the hemodynamic status, fluids with less chloride (eg, 0.45% saline) should be considered to avoid or minimize the development of hyperchloremic metabolic acidosis. The corrected serum sodium should also be used to guide fluid selection.
4. Add glucose to fluids when glucose is 250-300 mg/dL (13.9-16.7 mmol/L) in DKA. Administer 10% dextrose if necessary to maintain glucose >150 mg/dL (>8.3 mmol/L). In HHS, add glucose to fluids when glucose is 300 mg/dL (16.7 mmol/L) to maintain the glucose concentration between 250-300 mg/dL (13.9-16.7 mmol/L).

Insulin

1. Administer a regular insulin loading dose as an intravenous bolus (0.1-0.15 units/kg), followed by an infusion at 0.1 units/kg/h. If potassium concentration is <3.3 mmol/L, hold insulin until potassium is replaced.
2. If the glucose concentration does not fall by 50 mg/dL (2.8 mmol/L) in the first hour, consider increasing the insulin infusion rate or administering additional insulin boluses (10 units regular insulin hourly). Lack of response may also be due to inadequate volume resuscitation or serious infection.
3. In DKA, continue insulin infusion or decrease by 50% when the glucose reaches 250 mg/dL (13.9 mmol/L). Maintain the glucose concentration between 150 and 200 mg/dL (8.3 and 11.1 mmol/L) until acidosis and ketosis are resolved.
4. In HHS, decrease insulin infusion when the glucose concentration reaches 300 mg/dL (16.7 mmol/L) to maintain the glucose at 250-300 mg/dL (13.9-16.7 mmol/L) until the plasma osmolality is ≤315 mOsm/kg and the patient is alert.

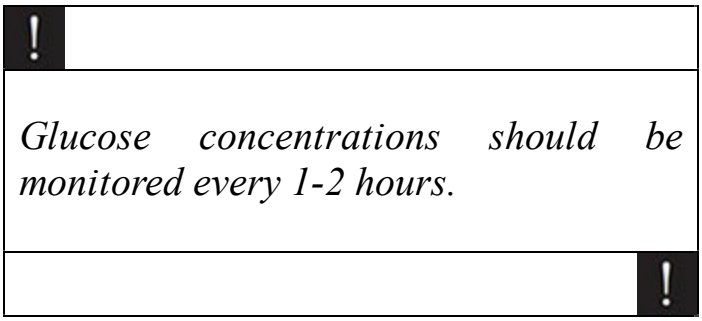
Electrolytes

1. If serum potassium is <3.3 mmol/L, hold insulin and administer potassium, 40 mmol/h as potassium chloride or potassium phosphate (or combination), until potassium is >3.3 mmol/L to avoid arrhythmias or severe weakness.
2. If serum potassium is >3.3 mmol/L but <5 mmol/L and urine output is adequate, administer potassium, 20-30 mmol, in each liter of fluids to maintain the potassium at 4-5 mmol/L.
3. If serum potassium is >5 mmol/L, do not administer potassium in fluids until <5 mmol/L.
4. Consider phosphate replacement with potassium phosphate if serum levels are low (<1 mg/dL, 0.32 mmol/L) or severe symptoms are present.

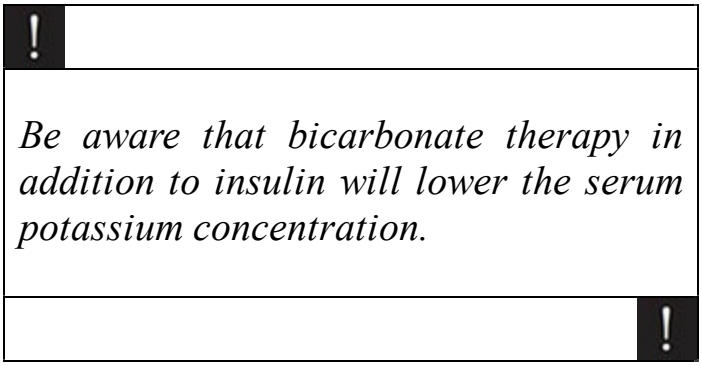
Abbreviations: DKA, diabetic ketoacidosis; HHS, hyperglycemic hyperosmolar state

The intravenous route for insulin administration is the most reliable and easiest to titrate. Because of the short half-life of intravenous insulin, a continuous infusion is necessary with serial monitoring of the glucose and electrolyte concentrations. Smaller doses of insulin may be adequate in HHS. In the case of DKA, insulin infusion should be continued until the removal of beta-hydroxybutyrate and acetone, as measured by normalization of the anion gap. Normalization of the anion gap usually occurs many

hours after normalization of the serum glucose levels.



Glucose-containing fluids may be started earlier than recommended if blood glucose cannot be monitored frequently. When glucose and/or serum osmolality are controlled, acidosis has cleared, and the patient is stable, subcutaneous insulin may be administered; an insulin sliding scale of regular and longer-acting preparations can be started and should overlap for 1 to 2 hours with discontinuation of the insulin infusion.



Insulin and correction of acidosis shifts potassium intracellularly and may lead to precipitous drops in serum potassium levels. Oral potassium replacement can be considered if nausea and vomiting are not present. Potassium and other electrolyte levels should be monitored frequently (especially in the first 6 hours) until levels stabilize and acidosis is resolved.

Acidosis is well tolerated by patients with DKA, and bicarbonate therapy is controversial. No benefit has been found when bicarbonate is administered to DKA patients with pH of 6.9 to 7.1, and fluid and insulin therapy results in rapid improvement in pH. Bicarbonate administration may be considered if the arterial pH is <6.9 (give 100 mmol bicarbonate over 1 hour to increase pH >7). Do not attempt to normalize blood pH with bicarbonate, because acidosis resolves as ketones are metabolized.

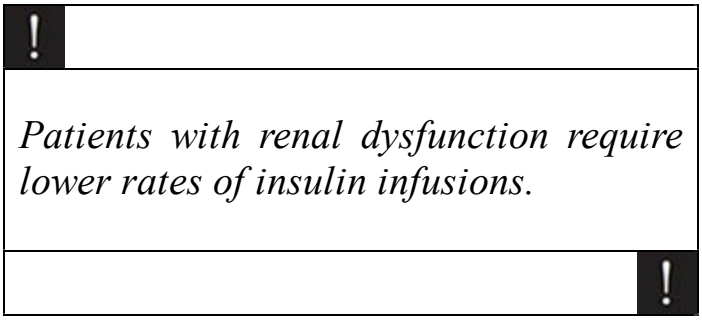
2. Hyperglycemia in Critical Illness

Hyperglycemia is common in diabetic and nondiabetic patients with critical illness and

may be due to stress hormones, inflammatory mediators, glucocorticoid therapy, excessive nutritional calories, decreased activity, and other mechanisms. Significant hyperglycemia is associated with poor wound healing, impaired immune function, increased inflammation, endothelial dysfunction, and other adverse effects leading to increased illness and death. Early studies of tight glucose control (80-110 mg/dL, 4.4-6.1 mmol/L) suggested benefit in a surgical population, but this target has been difficult to achieve in subsequent studies without increasing the risk for severe hypoglycemia. In addition, in multiple subsequent trials, no consistent reduction in mortality was observed with intensive control of glucose levels. Some recent studies of tight glycemic control have actually demonstrated increased mortality associated with higher rates of hypoglycemia.

In critically ill patients, insulin therapy should be initiated for persistent hyperglycemia. Once it has been initiated, a glucose of less than 180 mg/dL (7.8-10 mmol/L) with the avoidance of hypoglycemia is recommended. Intravenous insulin infusions are the preferred method to achieve and maintain control. During intravenous insulin therapy, frequent monitoring of blood glucose is essential to minimize the risk of hypoglycemia and achieve optimal control.

The ability to provide adequate nursing support and monitoring may affect the blood glucose goals chosen. Different types of blood sampling and glucose measurement methods may also yield different results. The institution's protocol for blood sampling, insulin infusion, and glucose management targets should be followed to achieve consistency and minimize the risk of hypoglycemia.




Key Points

Management of Life-Threatening Electrolyte and Metabolic Disturbances

- In the presence of life-threatening dysrhythmias or paralysis associated with hypokalemia, give potassium chloride, 20 mmol/h, through a central venous catheter.
- If hyperkalemia-associated ECG abnormalities are present, administer calcium chloride or calcium gluconate intravenously over 5 to 10 minutes, then consider shifting potassium intracellularly with 50% dextrose and regular insulin intravenously, inhaled β-agonists, and/or sodium bicarbonate.
- In symptomatic euvolemic hyponatremia, limit the increase in serum sodium to 6 to 8 mmol/L in the first 24 hours. Too-rapid correction of serum sodium may result in CNS injury.
- Patients with hypernatremia and hemodynamic instability should have normal saline administered until intravascular volume is corrected. Subsequently, replace water with 5% dextrose in water, 0.45% NaCl, or 0.2% NaCl with 5% dextrose. Enteral replacement with water is an effective strategy in stable patients.
- Emergent treatment with a glucocorticoid is indicated in critically ill patients with vasopressor-resistant shock, even if the diagnosis is not established.
- The goals of treatment in hyperglycemic syndromes are to restore the fluid and electrolyte balance, provide insulin, and identify precipitating factors.
- In diabetic ketoacidosis, insulin infusion should be continued until the ketosis and acidosis have resolved. Glucose-containing fluids should be administered to prevent hypoglycemia during insulin infusion.
- Maintain the glucose between 250 and 300 mg/dL (13.9-16.7 mmol/L) in hyperglycemic hyperosmolar syndrome until the plasma osmolality is <315 mOsm/kg and the patient is alert.
- Potassium should be added to the fluid therapy for hyperglycemic syndromes as soon as serum potassium is recognized to be <5 mmol/L and urine output is adequate.
- A protocol of blood sampling, insulin infusion, and target glucose levels should be followed to avoid hyperglycemia and minimize hypoglycemia in critically ill patients.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

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11. Moghissi ES, Korytkowski MT, DiNardo M, et al. American Association of Clinical Endocrinologists and American Diabetes Association consensus statement on inpatient glycemic control. *Diabetes Care*. 2009;32:1119-1131.
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Suggested Website

1. Society Critical Care Medicine. http://www.SCCM.org/Guidelines

SPECIAL CONSIDERATIONS

Objectives

- Outline the diagnosis and management of pulmonary embolism.
- Describe appropriate prophylactic therapy for venous thromboembolism.
- List general management principles of severe gastrointestinal hemorrhage.
- Describe appropriate prophylactic therapy for the prevention of stress-related gastritis.
- Summarize the principles of poisoning management.
- Review the management of hypertensive crises.
- Outline the diagnosis and management of intra-abdominal hypertension and abdominal compartment syndrome.

Case Study

An obese woman (body mass index of 40) with chronic tobacco abuse and congestive heart failure arrives at the emergency department complaining of shortness of breath and right pleuritic chest pain for the past 2 days. She has a heart rate of 110 beats/min with clear lung fields and mild bilateral pretibial edema. When she arrived, her oxygen saturation on pulse oximetry (Spo_2) with room air was 89%; that has increased to 94% on oxygen, 3 L/min by nasal cannula. A chest radiograph did not show any infiltrates. You are called for assistance in her management.

– What is the differential diagnosis based on the patient's risk factors and clinical findings?

– What tests are indicated?

I. INTRODUCTION

In addition to the medical conditions discussed in previous chapters, the clinician may be called on to care for patients with other severe and/or life-threatening problems. The management and prevention of some of these commonly encountered conditions are reviewed in this chapter.

II. PULMONARY EMBOLISM

A. Diagnosis

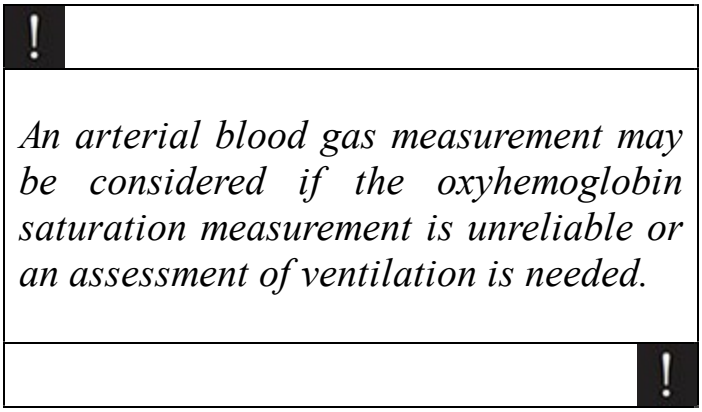
A patient's history and clinical findings may be unreliable for diagnosis of a pulmonary embolism (PE). Risk factors for PE and other venous thromboembolic diseases (**Table 13-1**) often contribute to a high index of suspicion. Predisposing factors include any condition that may cause venous stasis, injury to the vascular endothelium, or hypercoagulability (Virchow triad).

Table 13-1 Risk Factors for Pulmonary Embolism/Venous Thromboebolism

Family history	Central venous catheterization
Advanced age	Recent surgery
Obesity (body mass index >30)	Immobility, paralysis
Prior history of deep vein thrombosis/pulmonary embolism	Stroke with partial or full paralysis
Venous insufficiency	Trauma
Venous injury or repair	Malignancy (past or current)
Inherited hypercoagulable disorders	Cancer therapy
(protein C or S deficiency, lupus anticoagulant, etc)	Selective estrogen receptor modulators
Acute medical illness, ICU admission	Pregnancy and postpartum period
Heart or respiratory failure	Estrogen therapy
Nephrotic syndrome	Smoking

The classic combination of dyspnea, pleuritic chest pain, and hemoptysis occurs in a minority of patients with PE. Routine blood studies are not diagnostic. Chest radiographs are frequently unremarkable but may show nonspecific findings of atelectasis, pleural effusion, elevated hemidiaphragm, and/or infiltrates. Chest

radiographs may be useful in ruling out other life-threatening problems, such as pneumothorax. The electrocardiogram (ECG) may show nonspecific ST-T wave changes, QR pattern in lead V_1, an $S_1Q_3T_3$ pattern, or right bundle-branch block, but a pattern of acute cor pulmonale is generally not present.



An arterial blood gas measurement may be considered if the oxyhemoglobin saturation measurement is unreliable or an assessment of ventilation is needed.

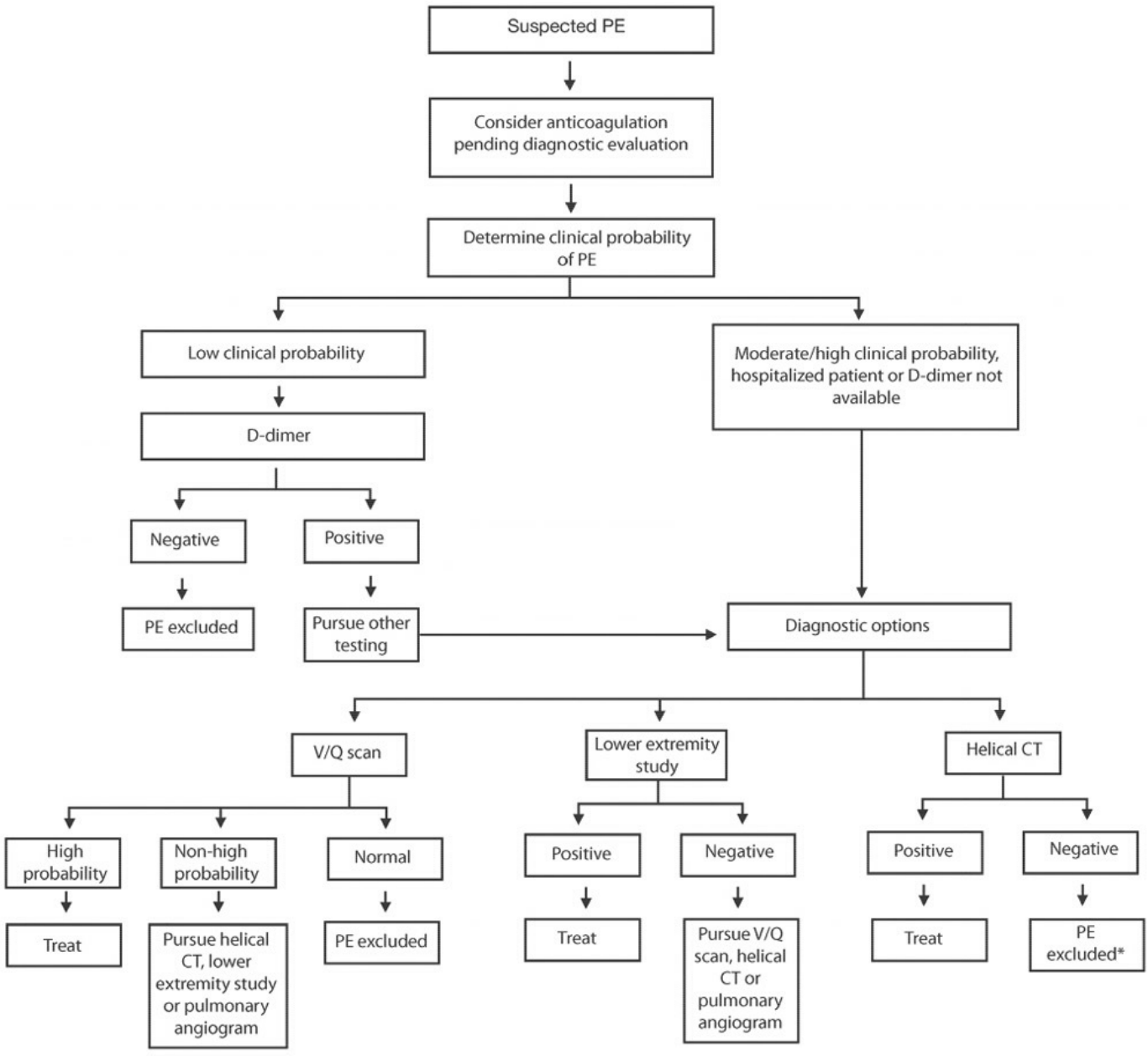
Sinus tachycardia and premature atrial contractions are the most frequently encountered dysrhythmias. Often the most relevant information provided by the ECG is the exclusion of other potential sources of chest pain, such as acute ischemia or pericarditis. Hypoxemia, a nonspecific finding in cardiopulmonary disease, is commonly present, but a normal Pa_{O_2} value or normal alveolar-arterial oxygen partial pressure difference [$P(A - a)_{O_2}$] does not rule out PE. Signs and symptoms of PE are shown in **Table 13-2**.

Table 13-2	Clinical Manifestations of Pulmonary Embolism
Dyspnea	Fever (usually low-grade)
Chest pain	Hypoxemia
Cough	Cyanosis
Tachypnea	Apprehension
Tachycardia	Syncope
Diaphoresis	Previously noted leg swelling
Hemoptysis	

A correct diagnosis of PE is essential because early initiation of appropriate therapy decreases mortality. The current diagnostic strategy recommends that the clinician formulate a clinical likelihood of low, moderate, or high clinical suspicion of PE (**Figure 13-1**). One scoring system used to determine pretest probability is presented in **Table 13-3**. D-dimer assays with high sensitivity and high negative predictive value are frequently used as an initial step in algorithms for the diagnosis of PE in outpatients. A negative D-dimer result in a patient with low clinical probability of PE may reliably

exclude the diagnosis. Patients with a positive D-dimer result or with a moderate or high clinical probability assessment require further diagnostic evaluation. D-dimer measurements have limited utility for the evaluation of PE in hospitalized, critically ill, injured, and postoperative patients because of the high proportion of positive results.

Figure 13-1. A Diagnostic Approach to Pulmonary Embolism



[a]Consider pulmonary angiogram if clinical suspicion is high; negative predictive value is increased by a negative lower extremity study
Abbreviations: PE, pulmonary embolism; CT, computed tomography; $\dot{V}/\dot{Q}$, ventilation/perfusion

Table 13-3	Clinical Probability Assessment for Pulmonary Embolism

Clinical signs and symptoms of DVT (objective new onset, leg swelling with palpation)	3
PE as likely, or more likely, than an alternative diagnosis	3
Immobilization (bed rest, except to access bathroom, for ≥3 consecutive days or surgery in the previous 4 weeks)	1.5
Previous objective diagnosis of DVT or PE	1.5
Heart rate >100 beats/min	1.5
Hemoptysis	1
Active cancer (treatment ongoing or within previous 6 months or palliative treatment)	1
0-1: Low probability 2-6: Moderate probability ≥7: High probability	

Abbreviations: PE, pulmonary embolism; DVT, deep venous thrombosis

Multidetector computed tomography angiography demonstrating thrombus up to the segmental-level pulmonary arteries is diagnostic for PE, whereas a negative scan can be safely used to exclude it. In patients with an allergy to contrast, venous lower limbs Doppler scanning can be used to aid in the diagnosis of thromboembolism, and further diagnostic testing is not needed as therapy is similar to that for PE. A negative Doppler exam does not rule out deep venous thrombosis (DVT) since the majority of PEs originate from the iliac veins. A ventilation/perfusion ($\dot{V}/\dot{Q}$) scan can be used to aid in the diagnosis in patients who can't receive intravenous contrast. A normal $\dot{V}/\dot{Q}$ scan can exclude PE. Similarly, a high probability $\dot{V}/\dot{Q}$ scan establishes the diagnosis of PE. In all other combinations of $\dot{V}/\dot{Q}$ scan and clinical suspicion, further tests are performed. Bedside echocardiography can be used to infer the diagnosis but is only diagnostic if it shows new-onset right ventricular dilatation or strain. A normal echocardiogram does not rule out PE.

B. Therapy

The treatment of PE can usually be limited to anticoagulation, starting with initial administration of a parenteral agent (low-molecular-weight heparin [LMWH], unfractionated heparin, fondaparinux). LMWH and fondaparinux can be effective in treating PE and are preferred over unfractionated heparin due to convenient dosing, absence of need for laboratory monitoring, and low incidence of heparin-induced thrombocytopenia. Both agents are dosed based on weight and require dosage adjustment with renal impairment. Unfractionated heparin is preferred in patients with severe renal dysfunction, those at high risk of bleeding, and when thrombolytic therapy is being considered. In patients with suspected PE and no contraindications to anticoagulation, baseline-activated partial thromboplastin time, prothrombin time, and

complete blood cell count should be obtained, and heparin or fondaparinux therapy should be initiated while waiting for test results unless there is a high risk of bleeding. Contraindications to heparin therapy include recent major trauma with hemorrhage, recent central nervous system hemorrhage or infarction, active gastrointestinal (GI) bleeding, and heparin-induced thrombocytopenia. When unfractionated heparin is used, the activated partial thromboplastin time should be monitored to achieve a value 1.5 to 2.5 times the mean normal value.

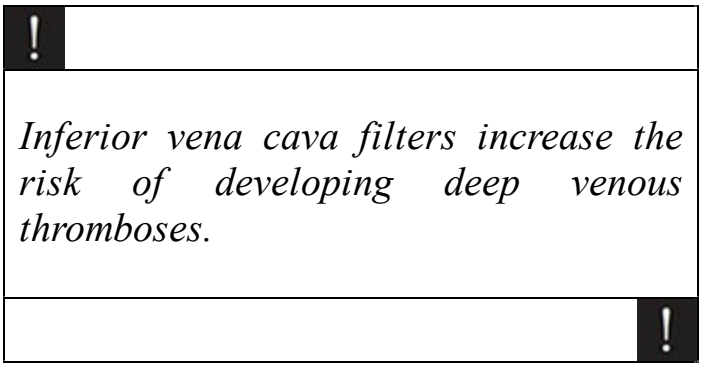
Oral warfarin therapy is started on day 1 and adjusted to achieve an international normalized ratio of 2 to 3. Heparin or fondaparinux therapy can be discontinued after 5 days if the international normalized ratio is 2 or above for at least 24 hours with warfarin. Oral anticoagulation should continue for at least 3 months, but some patients (those with unprovoked first PE/DVT or recurrent unprovoked PE/DVT) may have indications for longer therapy unless there is a high risk of bleeding. For patients with underlying malignancy, extended therapy with LMWH is suggested over warfarin, but the choice of agent may be influenced by costs, tolerance of injections, and need for monitoring. In patients who receive long-term anticoagulant treatment, the risk/benefit ratio of continuing such treatment should be reassessed at regular intervals.

In the last decade, new options for anticoagulation have become available in the form of direct oral anticoagulation (DOAC), providing a greater number of agents for the prevention and treatment of thromboembolic disease. These anticoagulants can directly target the enzymatic activity of thrombin and factor Xa. The direct thrombin inhibitors prevent thrombin from breaking the fibrinogen into fibrin; they bind directly to thrombin. Examples are bilavirudin, argatroban, and dabigatran (oral agent). The direct factor Xa inhibitors prevent factor Xa from breaking prothrombin into thrombin; they bind directly to factor Xa. Examples are rivaroxaban and apixaban

The overall mortality from DOAC appears to be lower than that from warfarin, primarily because of a decrease in intracranial bleeding. DOAC is generally used without a requirement for monitoring of drug levels or coagulation (clotting) times. This can be an advantage for patients for whom frequent monitoring is required. Whether laboratory monitoring of any of the DOAC agents can further improve their efficacy or safety remains to be seen. The reversal of the anticoagulation effect of DOAC is more difficult than with heparin and warfarin.

Systemic thrombolysis for PE may improve pulmonary arterial hemodynamics, lung perfusion, and right ventricular function, but the quality of evidence suggesting improved mortality is low. The use of thrombolytic agents in the treatment of PE should take into account the patient's hemodynamic status, right ventricular function, and risk of bleeding. Systemic thrombolytic therapy is currently suggested for patients with acute

PE with hypotension who are at low risk of bleeding. Thrombolysis is not recommended for most hemodynamically stable patients with PE. Although thrombolysis is suggested for a subgroup of patients with a high risk of developing hypotension, there are no validated clinical findings that can be used to identify such patients. Multiple clinical signs such as tachycardia, decrease in blood pressure, hypoxemia, evidence of hypoperfusion, and right ventricular dysfunction can be considered in decision making. Tissue plasminogen activator is preferred at a dose of 100 mg infused over a 2-hour period. Streptokinase has also been used with a loading dose of 250,000 international units, followed by 100,000 international units each hour for 24 hours. Short administration times are preferred over prolonged infusion times. Recently, interest has been renewed in pulmonary artery, catheter-directed instillation of thrombolytic agents. Surgical embolectomy or extraction/fragmentation of the embolus via transvenous catheters requires specialized expertise not commonly available, but it can be considered when shock is likely to cause death before thrombolytics can affect clot dissolution or systemic administration of thrombolytic agents is risk-prohibitive.



An inferior vena cava filter should be considered in patients with PE when:

- Anticoagulation is strongly contraindicated
- Emboli recur during anticoagulation
- Bleeding occurs during anticoagulation
- Physiologic reserve is insufficient to withstand a recurrent PE

Retrievable filters may be an option in some centers. If possible, anticoagulation for treatment of the embolus should be resumed as soon as possible after insertion of a filter.

C. Prevention of Venous Thromboembolism

Case Study

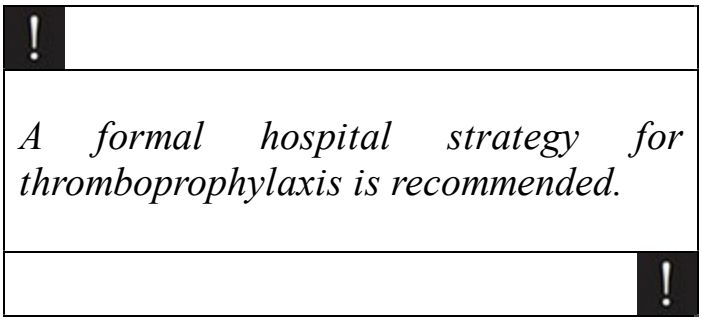
A middle-aged man presents with an acute ischemic stroke and right hemiparesis. He received tissue plasminogen activator and experienced improvement in the neurologic deficits.

– Should this patient receive prophylaxis for venous thromboembolism?

– What type of venous thromboembolism prophylaxis would be appropriate if the decision were made to treat?

Many critically ill or injured patients are at risk of developing venous thromboembolism, either PE or DVT. The development of thrombosis can lead to longer hospital stays, increased resource utilization, venous insufficiency, and death. Thromboprophylaxis is cost-effective and highly efficacious in preventing venous thromboembolism. Both pharmacologic (heparins, direct thrombin inhibitors such as fondaparinux and dabigatran [not approved for this indication in United States], factor Xa inhibitors such as rivaroxaban and apixaban, and warfarin) and mechanical interventions (intermittent pneumatic compression device, graduated compression stockings) may be used for prophylaxis in hospitalized patients. Mechanical methods for prophylaxis are generally less effective but are acceptable options for patients at high risk of bleeding and when combined with anticoagulants.

Recommendations are based on specific patient groups (nonsurgical, nonorthopedic surgical, orthopedic surgical), level of risk for venous thromboembolism, and risk of bleeding. Clinicians should follow manufacturers' instructions for dosing of LMWH, especially in the setting of renal failure and obesity. Caution must be used when instituting anticoagulant therapy in patients with recent or ongoing hemorrhage, renal failure, or concomitant use of antiplatelet therapy.



III. SEVERE GASTROINTESTINAL HEMORRHAGE

Case Study

A 64-year-old man with arthritic pain had been taking ibuprofen four times daily for months without significant relief. He starts to complain of fatigue and progressive weakness. Today he developed nausea and started vomiting bright red blood. He called an ambulance and was brought to the emergency department. He is pale, tachycardic, and dizzy with a blood pressure of 95/60 mm Hg and hematocrit of 28%.

– What additional clinical and laboratory assessments are indicated?

– How would you prioritize interventions?

A. General Management Principles

Medications for ulcer prophylaxis and treatment have reduced the incidence of stress gastritis and severe upper GI bleeding. However, when present, such bleeding can be life-threatening and requires early gastroenterologic and surgical consultation as well as rapid assessment, diagnosis, and intervention. The distinction between upper and lower GI sources of hemorrhage is important in determining the appropriate diagnostic/therapeutic approach. The ligament of Treitz is the anatomic marker that separates the upper GI tract from the lower GI tract when discussing hemorrhage.

Typically, patients with life-threatening GI hemorrhage are older and have other chronic organ system disease(s). Therefore, the critical consequences of hemorrhage, hypotension, and anemia may be poorly tolerated and may lead to other systemic manifestations of poor oxygen delivery, such as myocardial ischemia and renal failure. Prompt assessment, resuscitation, early diagnosis (even during resuscitation), and intervention are needed to prevent these secondary consequences.

> *An ECG should be obtained in patients with GI bleeding and heart disease or advanced age to assess for myocardial ischemia.*

A general approach to managing GI bleeding is outlined in **Table 13-4**. Obtain blood for

typing and cross matching as soon as possible. An appropriate hemoglobin level should be maintained based on patient condition and coexisting disease. Two large-bore peripheral catheters or a large-bore central venous catheter should be maintained at all times. Gastroenterology and surgery consultations (in case of severe bleeding) should be requested. If a reserve of blood products (eg, four units packed red cells) is not immediately available, early patient transfer should be planned.

Table 13-4 Management of Gastrointestinal Bleeding

Assessment	Airway Protective reflexes Level of consciousness Volume status Vital signs, orthostatic changes Central venous pressure Urine output Severity of condition Visible blood loss Hemoglobin, hematocrit, platelet count Coagulation status (APTT, PT) Hypoperfusion abnormalities (ie, cardiac ischemia) Nasogastric or orogastric tube Confirm or rule out upper GI source Lavage stomach for upper endoscopy
Resuscitation	Consider intubation Altered mental status Inability to protect airway Copious hematemesis Need for sedation/endoscopy IV access Large-bore (≥16 gauge) peripheral catheter(s) or large central venous catheter (9F-12F) Fluid administration Normal saline or lactated Ringer solution Transfusion of red blood cells
Diagnostic/Therapeutic Interventions	Endoscopy with directed therapy Radiolabeled red blood cell scan, CT angiogram, or conventional angiography to localize the site of lower GI bleeding Surgical assessment/intervention Correct coagulopathy Administer plasma, prothrombin complex concentrate, or other appropriate reversal agent Platelet transfusion if <50,000/mm^3 Pharmacologic therapy for variceal bleeding IV proton pump inhibitors Transfer to facility with diagnostic and/or therapeutic capability
Continuing Care	Monitored environment Adequate blood bank resources

	Frequent assessment Volume status Hypoperfusion abnormalities Laboratory parameters

Abbreviations: APTT, activated partial thromboplastin time; PT, prothrombin time; GI, gastrointestinal; CT, computed tomography

B. Severe Upper Gastrointestinal Hemorrhage

Severe upper GI hemorrhage is diagnosed by hematemesis or the presence of blood in the gastric aspirate, although 10% to 15% of patients with duodenal ulcer may have little or no blood in the gastric aspirate due to bleeding below the level of the pylorus. When obtaining a patient's history and physical examination, it is important to note previous upper GI bleeding, the presence of ulcer disease, alcohol consumption, stigmata of cirrhosis, coagulation disorders, and use of aspirin and other antiplatelet medications, nonsteroidal anti-inflammatory agents, or anticoagulants. Upper GI hemorrhage is categorized as variceal (VUGIH) and nonvariceal hemorrhage (NVUGIH) because of differing prognoses and managements. Common causes of NVUGIH include duodenal and gastric ulcers, Mallory-Weiss tear, malignancy, and gastritis.

Endoscopy is needed to establish the diagnosis and control hemorrhage. If this procedure is not quickly available, consider transfer to a facility with endoscopic capabilities. In patients taking anticoagulants, correction of coagulopathy is recommended but should not delay early endoscopy.

When uncontrolled variceal bleeding is suspected before endoscopic diagnosis, the following splanchnic vasoconstrictors may be considered:

- Somatostatin, 250-μg bolus, followed by 250 μg/h
- Octreotide, 25- to 100-μg bolus, followed by 25 to 50 μg/h
- Vasopressin, 20 units over 20 minutes, followed by 0.1 to 0.4 units/min
- Terlipressin, 1 to 2 mg every 4 hours (not available in the United States)

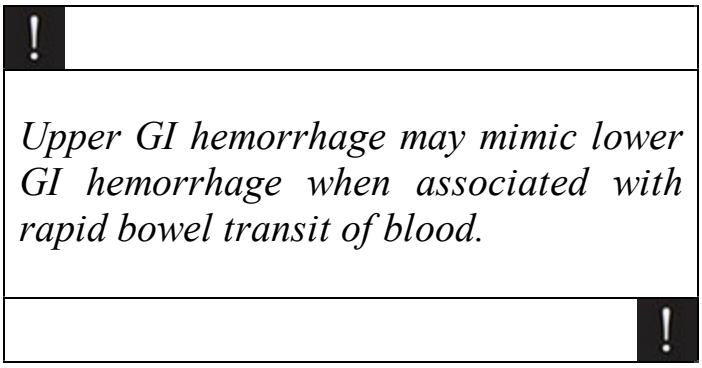
Somatostatin or a somatostatin analogue, such as octreotide, is the agent of choice because of the favorable side-effect profile. Nausea and abdominal pain are sometimes associated with bolus doses, but significant adverse effects are uncommon. Maintenance infusions are usually continued for 3 to 5 days and may be effective in stopping acute variceal bleeding and preventing early rebleeding from varices. High-dose vasopressin

is an alternative but may cause coronary artery vasospasm, angina, or hypertension. Concomitant nitroglycerin may prevent the deleterious effects of vasopressin on the coronary circulation. Terlipressin is a synthetic vasopressin analogue with fewer side effects and a longer half-life. None of the above agents are recommended in the routine management of NVUGIH. Antibiotics – usually a second or third-generation cephalosporin – should be administered in cirrhotic patients with VUGIH to protect against spontaneous bacterial peritonitis. If variceal hemorrhage cannot be controlled, balloon tamponade can be considered as a temporizing measure (maximum 24 hours) if expertise in placement is available until more definitive therapy, such as a porto-venous shunt, can be instituted. This often necessitates urgent transfer to a regional center.

Following endoscopy, an IV bolus of a proton pump inhibitor, followed by continuous infusion for 72 hours, is effective in decreasing NVUGIH repeat bleeding and mortality due to peptic ulcer disease. Pre-endoscopic administration of a proton pump inhibitor may reduce the need for endoscopic therapeutic interventions, particularly if endoscopy is delayed. If endoscopy is unsuccessful in controlling the bleeding, surgical intervention or angiographic embolization may be needed for control.

C. Severe Lower Gastrointestinal Hemorrhage

Frequent causes of lower GI hemorrhage are diverticular disease, angiodysplasia, large hemorrhoids, colonic polyps, inflammatory bowel disease, rectal ulcer/tear, upper GI source, and malignancy. Evaluation should include special attention to a history of diverticular disease, inflammatory bowel disease, previous abdominal aortic aneurysm repair (may suggest life-threatening aortoenteric fistula), or the presence of a coagulation disorder. Physical examination must include inspection and a careful rectal examination to identify hemorrhoids or rectal/anal carcinoma.



Gastric aspiration should be performed to eliminate an upper GI source of hemorrhage. A nasogastric aspirate that is negative for occult blood and contains bile makes an upper GI bleeding source unlikely. Upper GI endoscopy may be considered based on

assessment of the most likely bleeding source. Lower GI endoscopy is important for diagnosis and assessment of potential for rebleeding in addition to planning other diagnostic interventions or surgery. Although lower GI endoscopy may offer a therapeutic means to arrest hemorrhage, its role as a therapeutic intervention decreases as the rate of bleeding increases. Besides lower endoscopy, the use of CT angiography, radionuclide imaging scan, and angiography with embolization therapy should be considered for unstable patients or those who are poor surgical risks.

D. Prevention Of Stress-related Gastritis

Identification and treatment of patients at risk for stress-related gastritis will reduce complications, length of stay, and costs. To minimize the potential complications of pharmacologic prophylaxis for stress ulceration (ie, nosocomial pneumonia), routine use of such therapy should be limited to patients with known risk factors for stress gastritis. The risk of stress ulceration and GI bleeding depends on a patient's underlying illness, its severity, and related comorbidities. Significant risk factors include mechanical ventilation for longer than 48 hours, coagulopathy, severe infection, hypotension, severe head trauma (Glasgow Coma Scale score <10), severe burns or trauma, renal or hepatic failure, major surgery, and prolonged ICU stay. Appropriate therapeutic agents include histamine receptor-blocking agents (H_2-receptor antagonists) and proton pump inhibitors.

IV. POISONING AND DRUG TOXICITY

Case Study

A young woman was found on the bathroom floor by her parents the morning after a party. She was difficult to arouse and, when she was stimulated, she became agitated and violent. Her parents transported her to the emergency department.

– What are the immediate priorities and interventions in caring for this patient?

– What are the likely toxins, based on the patient's history and clinical presentation?

Patients who have ingested prescription, over-the-counter, or recreational drugs present with a variety of clinical manifestations. General categories of patient presentation and possible responsible agents are listed in **Table 13-5**. Reliable information about the substance(s), amount(s) ingested, and time of ingestion is often not available. Similarly,

although qualitative urine toxicology screens and quantitative blood tests may be available, they cannot identify all agents that could have been ingested. Quantitative drug levels should be obtained if the patient's medication or medical history suggests ingestion of a specific drug, or if the signs and symptoms are compatible with toxicity from that drug. Acetaminophen levels should be checked in all cases. The anion gap should be calculated in cases of unknown toxins.

Table 13-5	Clinical Characteristics That Aid in Diagnosis of Poisoning/Overdose
Clinical Examination	**Possible Agents**
Agitation, confusion, bizarre behavior	Cocaine, amphetamines, antidepressants, phencyclidine, hallucinogens, SSRIs
Bradycardia/hypotension	β-Blockers, barbiturates, calcium-channel blockers, clonidine, digoxin, sedatives/hypnotics
Coma, lethargy	Alcohols, antidepressants, barbiturates, benzodiazepines, gamma-hydroxybutyrate, lithium, opiates, salicylates, SSRIs
Hyperadrenergic, hyperthermia	Amphetamines, anticholinergics, cocaine, theophylline
Hypotension	Antidepressants, anticholinergics, opiates, organophosphates/carbamates, sedatives, hypnotics
Hypothermia	Ethanol, hypoglycemic agents, opiates, sedatives/hypnotics
Miosis	Cholinergic drugs, opiates, organophosphates, phencyclidine
Mydriasis	Antihistamines, atropine, tricyclic antidepressants, ethanol, sympathomimetic drugs
Nausea/vomiting	Acetaminophen, alcohols, iron, salicylates, theophylline
Nystagmus	Alcohols, carbamazepine, phenytoin, phencyclidine, sedative/hypnotics
Seizures	Amphetamines, antidepressants, cocaine, cyanide, isoniazid, lithium, organophosphates/carbamates, salicylates, SSRIs, theophylline
Tachyarrhythmias	Amphetamines, antidepressants, caffeine, cocaine, digoxin, theophylline
Ventilatory compromise (respiratory acidosis)	Opiates, alcohols, antidepressants, barbiturates, benzodiazepines, gamma-hydroxybutyrate
Laboratory Tests	**Possible Agents**
Increased osmolar gap	Ethanol, methanol, ethylene glycol, acetone, isopropyl alcohol, propylene glycol
Increased oxygen saturation gap	Methemoglobinemia, carbon monoxide
Metabolic acidosis	Acetaminophen, salicylates, methanol/ethylene glycol, iron-isoniazid, carbon monoxide, cyanide, propylene glycol, propofol

Abbreviation: SSRI, selective serotonin reuptake inhibitor

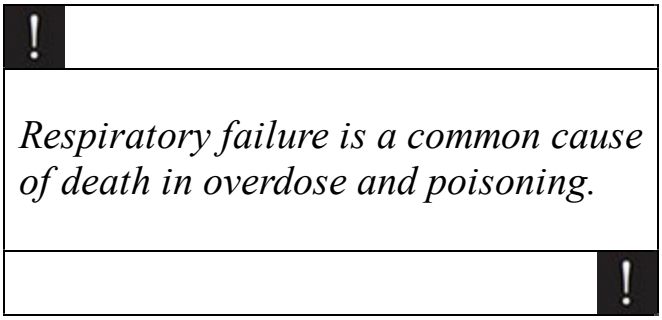
These patients often require a symptom-based initial evaluation and treatment. Specific

antidotes, treatments, and/or precautions based upon historical or laboratory evidence of particular ingestants can be utilized when applicable. In some countries, specialized resource centers are available to assist in the treatment of poisoning. The overall mortality from acute poisoning is low, but the treating clinician must quickly evaluate critical issues and attempt to identify patients at highest risk.

A. General Management

1. Initiate airway support as required. Assessing the patient to ensure adequate ventilation, oxygenation, and protective airway reflexes is critical.

2. Initiate management of cardiovascular compromise as indicated. Obtain adequate venous access and establish monitoring (eg, pulse oximeter, ECG, automated blood pressure device). Address initial concerns in monitored variables (eg, isotonic fluid administration, supplemental oxygen, seizure control, cooling or warming the patient, vasopressors, or inotropes).



3. Consider the following interventions for a patient with altered mental status:
    a. 50% dextrose (50 g), 50 mL intravenously, preferably after a blood glucose test.

    b. Naloxone, 0.2 to 2 mg, intravenously, intramuscularly, or via an endotracheal tube. Larger doses (6 to 10 mg), repeat dosing, or an infusion may be required, especially when synthetic and long-acting opiates are involved.

    c. Thiamine, 100 mg, slow intravenous administration. Administer before concentrated dextrose solutions to reduce the risk of Wernicke encephalopathy.

4. Little evidence exists for use of gastric-emptying procedures. Ipecac is not used in poisoned patients, and gastric lavage may be considered only in life-threatening overdoses within 1 hour of ingestion. Contraindications include an unprotected airway and ingestion of substances with high potential for aspiration injury,

including hydrocarbons and acid or alkali ingestions.

5. In patients with significant toxic ingestions, administer activated charcoal within 1 to 2 hours of ingestion at an initial dose of 1 g/kg. The effectiveness of activated charcoal decreases with time from ingestion, so early administration is indicated. Caution is required with decreased level of consciousness and an unprotected airway.

6. Be aware that although cathartics have been used in overdoses, there is no evidence of efficacy. Caution is warranted in the very young and elderly (because of potential fluid losses) and those with the potential for obstruction.

7. Recognize that hemodialysis, rather than continuous renal replacement therapy, is the preferred intervention in patients with life-threatening overdoses of dialyzable substances. Common dialyzable drugs include carbamazepine, valproic acid, lithium, toxic alcohols, salicylates, and metformin.

B. Specific Management

After the patient is stabilized, more specific therapy may be warranted. Specific antidotes and/or interventions that may be considered are listed in **Table 13-6**. The use of more advanced interventions, such as hemodialysis or hemoperfusion, should be individualized to each patient and may require consultation or transfer.

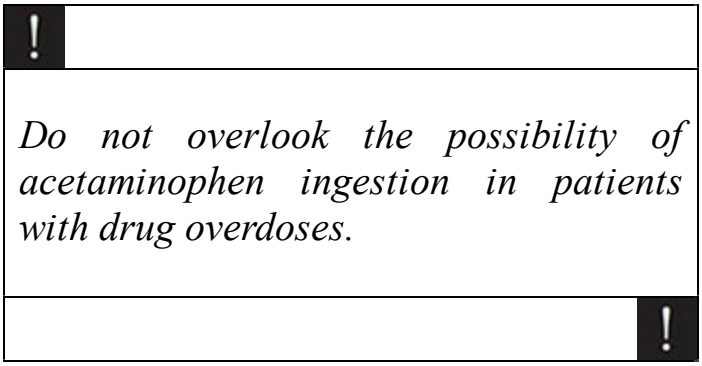


Table 13-6 Antidotes and Interventions for Specific Toxins

Toxin	Antidote or Intervention
Acetaminophen	N-acetylcysteine
Alcohols (methanol, ethylene glycol)	Ethanol, fomepizole, hemodialysis, thiamine and pyridoxine (vitamin B_6) for ethylene glycol, folic acid for methanol
Amphetamines	Benzodiazepines

Benzodiazepines	Flumazenil[a]
β-Blockers	Glucagon, calcium chloride, pacing, catecholamines, insulin and dextrose
Calcium-channel blockers	Calcium chloride, glucagon, insulin and dextrose, pacing, catecholamines
Carbon monoxide	100% oxygen, hyperbaric oxygen
Cocaine	Benzodiazepines
Cyanide	Nitrites and thiosulfate, hydroxocobalamin
Cyclic antidepressants	Benzodiazepines (for seizures), blood alkalinization/sodium loading (pH 7.5-7.55), hypertonic saline, magnesium, α-agonist for hypotension (norepinephrine)
Digoxin	Digoxin-specific Fab fragments, atropine, lidocaine, pacing
Heparin	Protamine sulfate
Hypoglycemic agents	50% dextrose, somatostatin or octreotide
Iron	Deferoxamine
Isoniazid	Pyridoxine (vitamin B_6)
Lithium	Hemodialysis
Nitrites	Methylene blue
Opiates	Naloxone, intubation/ventilation
Organophosphates, carbamates, nerve gases	Atropine, pralidoxime or obidoxime
Salicylates	Urine alkalinization, hemodialysis
Theophylline	Multiple-dose charcoal, hemoperfusion
Warfarins	Vitamin K_1

[a]Flumazenil should not be administered to patients who chronically ingest benzodiazepines or have overdosed on cyclic antidepressants.

V. HYPERTENSIVE CRISES

A. Clinical Presentation

Acute hypertension or severe elevation in blood pressure may occur as a primary or secondary condition in seriously ill patients. Frequently, patients have an underlying diagnosis of chronic hypertension. New or progressive end-organ injury secondary to elevation in BP constitutes a *hypertensive emergency*, while severely elevated BP without evidence of organ injury is defined as *hypertensive urgency*. Although the BP is

often >180/120 mm Hg, no specific BP defines a hypertensive emergency. The rate of blood pressure increase may be more important than the absolute value. The organs most severely affected by elevations of BP are the brain, heart, and kidney, and injury can manifest as encephalopathy, stroke, intracranial hemorrhage, unstable angina or myocardial infarction, acute left ventricular dysfunction (with pulmonary edema), acute aortic dissection, and deteriorating renal function. Hypertensive disorders associated with pregnancy are discussed elsewhere (see **Chapter 14**).

Symptoms related to an elevated BP at presentation reflect the organ affected and consequent injury but may be nonspecific. The patient's history of use of monoamine oxidase inhibitors, recreational drugs (including cocaine and amphetamines), over-the-counter medications, and antihypertensive agents as well as medication compliance should be ascertained. Physical examination and laboratory investigation should be directed to determine the presence of end-organ injury. Initial workup usually includes complete blood count, renal function, urinalysis with microscopy, ECG to assess for cardiac ischemia, and chest radiography to evaluate for pulmonary edema or widened mediastinum. Patients with altered mental status or focal neurological deficits warrant imaging of the brain.

A complication of uncontrolled hypertension is acute aortic dissection. Symptoms are often severe and can include unrelenting chest pain, frequently associated with back or epigastric pain, and neurological deficits such as altered mental status, focal deficits, hemiplegia, and paraplegia. A patient with severe hypertension, severe chest pain radiating to the back, and a wide mediastinum on chest radiograph should be evaluated for possible aortic dissection. Aortic dissection is frequently misdiagnosed as acute myocardial infarction, PE, stroke, esophagitis, pancreatitis, peptic ulcer disease, biliary colic, and ureteral colic. Physical examination should include careful auscultation for a new murmur of aortic insufficiency, assessment for asymmetric blood pressure or pulses in upper extremities, and careful palpation of pulses in all extremities for significant asymmetry. The diagnostic standard has been contrast angiography, but computed tomography angiography is more commonly used. Magnetic resonance imaging and transesophageal echocardiography may also be useful for diagnosis.

Acute hypertension secondary to increased sympathetic drive and catecholamine surge is also a frequent manifestation of common disease processes in seriously ill patients, such as respiratory failure, acute pain, alcohol or drug withdrawal syndromes, agitated delirium, and increased intracranial pressure (Cushing reflex). Initial therapy in such circumstances should be targeted to treating the underlying problem and not lowering of elevated BP.

B. Therapy

Hypertensive urgency can be managed with oral or intravenous agents, and gradual blood pressure control over 24 to 48 hours. The goal is to reduce the pressure over hours to days to a safer, but not necessarily normal, level of BP. Hypertensive emergencies require continuous monitoring of BP, neurological status, urine output, and other parameters in a monitored environment. Parenteral and titratable antihypertensive agents should be administered to lower the BP within minutes to hours. The initial goal of therapy should be to reduce mean arterial pressure by no more than 20% to 25% in first few hours. If the BP is lowered too rapidly, it may result in hypoperfusion of major arterial beds, resulting in cerebral infarction, myocardial infarction, and blindness secondary to changes in autoregulation of organ blood flow.

Rapid-acting antihypertensives are preferred, including labetalol, esmolol, nitroprusside, nicardipine, nitroglycerin, and clevidipine. Agents that can be considered in some specific situations are given in **Table 13-7**. Oral antihypertensives appropriate for the patient can usually be initiated within 6 to 12 hours of presentation and parenteral agents weaned.

Table 13-7 Parenteral Antihypertensive Agents Used in the Management of Hypertensive Emergencies

Primary Condition	Therapy	Primary Condition	Therapy
Acute aortic dissection	Labetalol Esmolol Nicardipine	Diastolic dysfunction with pulmonary edema	Nicardipine Labetalol Fenoldopam Nitroglycerin Nitroprusside
Hypertensive encephalopathy	Labetalol Nicardipine Clevidipine Fenoldopam Nitroprusside	Acute ischemic stroke/ intracerebral bleed	Nicardipine Labetalol Fenoldopam Clevidipine
Acute myocardial ischemia	Nitroglycerin Labetalol Fenoldopam	Acute renal failure	Nicardipine Labetalol Fenoldopam
Systolic heart failure	Nicardipine Nitroglycerin Loop diuretic	Perioperative hypertension	Nicardipine Nitroglycerin Clevidipine Labetalol Esmolol
Eclampsia/severe preeclampsia	Hydralazine Labetalol Nicardipine		

Pheochromocytoma	Phentolamine Labetalol

Specific Situations:

1. In patients with acute aortic dissection, a rapid reduction of systolic BP to 100 to 120 mm Hg with a heart rate 60 to 80 beats/min should be achieved within 5 to 10 minutes. A beta-blocker or an agent with combined alpha- and beta-blockade, such as labetalol, is preferentially used in this condition to decrease the shear forces on the aorta and try to limit the extent of dissection. Additionally, opiate analgesics may be needed for pain control.
2. In patients with normal renal function and signs of volume depletion (due to pressure natriuresis), gentle volume expansion with normal saline will help suppress renin secretion and prevent significant hypotension from vasodilating medications.

VI. INTRA-ABDOMINAL HYPERTENSION AND ABDOMINAL COMPARTMENT SYNDROME

Increased intra-abdominal pressure (IAP), the pressure within the abdominal cavity typically measured as bladder pressure, has been increasingly recognized as both the cause and consequence of many complications in critically ill patients. The perfusion pressure to the abdomen, termed *abdominal perfusion pressure* (APP), is the mean arterial pressure minus the IAP. Similar to cerebral perfusion pressure, APP is the critical determinant of perfusion to the abdominal visceral organs.

Intra-abdominal hypertension (IAH) is defined as a sustained increase of IAP to >12 mm Hg, while abdominal compartment syndrome is defined as IAP >25 mm Hg with new onset of organ failure at a lower IAP.

While normal IAP is in the range of 3 to 7 mm Hg, it can reach 9 to 14 mm Hg in obese individuals. Hence, the physiologic state must be taken into account when interpreting IAP measurements. Increases can come from increased abdominal volume, decreased abdominal wall compliance, or more commonly a combination of the two. Some conditions leading to IAH/abdominal compartment syndrome are listed in **Table 13-8**. Abdominal compartment syndrome is classified as primary, secondary, or recurrent. Primary abdominal compartment syndrome is a condition associated with injury or disease in the abdominopelvic region that frequently requires early surgical or radiological intervention, whereas secondary abdominal compartment syndrome

develops from conditions that do not originate primarily from that region (eg, sepsis, capillary leak, burns). Abdominal compartment syndrome can progress and recur even after initial therapy is successful.

IAH has deleterious effects on both intra- and extra-abdominal organ systems. Most of these effects are either from decreased abdominal perfusion causing ischemia of abdominal organs or from reduced thoracoabdominal compliance leading to reduced cardiac output and respiratory compromise. Specifically:

1. Decreases in APP can cause acute kidney injury, splanchnic hypoperfusion, and gut ischemia. These effects may occur in the absence of decreased cardiac output.

2. Intrathoracic pressure increases secondary to reduced thoracoabdominal compliance and cephalad displacement of the diaphragm (20% to 80% transmission of abdominal pressure). This has negative effects on the cardiovascular, respiratory, and central nervous systems:
    a. Cardiovascular
        i. Decreased venous return leading to diminished preload and end-diastolic volume

        ii. Increased systemic afterload

    b. Respiratory
        i. Decreased total compliance

        ii. Increased inspiratory pressures or decreased tidal volumes, depending on the mode of mechanical ventilation

    c. Intracranial
        i. Increased intracranial pressures secondary to elevated thoracic pressures and diminished cerebral venous return

Significant IAH will lead to increased measured filling pressures, such as central venous pressure, secondary to reduced chest wall compliance; however, venous return is significantly reduced, and the transmural pressures are actually low. Thus, these values will have different interpretations with IAH, and higher physiological targets may be appropriate for resuscitation.

IAP measurements are made at end-expiration with the patient in the supine position, after ensuring that abdominal muscle contractions are absent and with the transducer zeroed at the level of the mid-axillary line. The reference standard for intermittent IAP measurement is via the bladder with a maximal instillation volume of 25 mL of sterile saline.

A. Management

The cornerstones of management of IAH/abdominal compartment syndrome are early recognition by serial monitoring of IAP (every 4 to 6 hours), maintenance of abdominal (APP >60 mm Hg) and systemic perfusion, prompt institution of medical therapies to reduce IAP and prevent adverse consequences on organ function, and early surgical decompression for refractory IAH. Patients with the risk factors for developing IAH (**Table 13-8**) should have their bladder pressure measured routinely. Physical exam alone is not sufficiently sensitive to be useful in the early detection of IAH.

Table 13-8 Conditions Associated with Intra-abdominal Hypertension/Abdominal Compartment Syndrome[a]

Increased Intra-abdominal Volume	Decreased Abdominal Wall Compliance	Combination
Gastrointestinal tract dilation • Ileus • Volvulus • Colonic pseudo-obstruction	Abdominal surgery, especially with tight abdominal closures	Obesity
Intra-abdominal or retroperitoneal masses • Abdominal tumor	Abdominal wall bleeding or rectus sheath hematomas	Sepsis, severe sepsis, and septic shock
Ascites or hemoperitoneum	Surgical correction of large abdominal hernias, gastroschisis, or omphalocele	Severe acute pancreatitis
Retroperitoneal edema/hemorrhage		Massive fluid resuscitation
Pneumoperitoneum (eg, during laparoscopy)		Major burns (with or without abdominal eschars)
		Complicated intra-abdominal infection

[a]Classified partly using Malbrain ML, Cheatham ML, Kirkpatrick A, et al. Results from the International Conference of Experts on Intra-abdominal Hypertension and Abdominal Compartment Syndrome. I. Definitions. *Intensive Care Med*. 2006;32:1722-1732.

Medical Therapies

1. Evacuate intraluminal contents by nasogastric or colonic decompression.
2. Evacuate intra-abdominal space-occupying lesions (eg, drainage of large volume ascites).
3. Optimize fluid administration and avoid both hypo- and hypervolemia. Consider

diuretics and renal replacement therapy in cases of hypervolemia.

4. Improve thoracoabdominal compliance by ensuring adequate sedation and analgesia, and drainage of pleural effusions and ascites. Avoid constrictive bandages, and consider neuromuscular blockade.

5. Ensure abdominal and systemic perfusion by keeping APP >60 mm Hg.

Surgical Therapy

1. Decompressive laparotomy is the "gold standard" and most definitive therapy for IAH. However, patients can develop recurrent IAH, even with an "open abdomen" if the temporary abdominal closure device used to protect the viscera is too tight.

Key Points

Special Considerations

- A negative result with a high-sensitivity D-dimer assay in outpatients with low clinical probability of PE can exclude the diagnosis, whereas those with moderate or high clinical probability and hospitalized patients require further diagnostic testing.
- In patients with suspected PE and no contraindications to anticoagulation, unfractionated or low-molecular-weight heparin or fondaparinux therapy should be initiated while diagnostic tests are being obtained.
- Patients at risk for venous thromboembolism should receive appropriate pharmacologic and/or mechanical prophylaxis.
- In facilities with limited blood bank capabilities, consideration should be given to transferring patients with serious GI bleeding to a facility with a higher level of care.
- Endoscopy is needed to establish the etiology of upper GI hemorrhage and to institute potentially definitive therapy.
- Lower GI endoscopy is important for diagnosing, possibly treating, and planning interventions for patients with severe lower GI hemorrhage.

- Patients at risk for stress-related gastritis should be started on an H_2-receptor antagonist or proton pump inhibitor.
- In the treatment of patients with known or suspected poisoning/overdose, maintaining airway patency and circulatory stabilization are the initial priorities.
- Control of blood pressure and heart rate is critical in the management of patients with aortic dissection.
- Intra-abdominal pressure should be monitored frequently in patients at risk for developing intra-abdominal hypertension and abdominal compartment syndrome.
- Therapy for control of intra-abdominal pressure and maintenance of abdominal and systemic perfusion should be initiated promptly.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

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Suggested Websites

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2. Institute for Clinical Systems Improvement. http://www.icsi.org.
3. World Society of Abdominal Compartment Syndrome. http://www.wsacs.org

CRITICAL CARE IN PREGNANCY

Objectives

- Describe the physiologic and metabolic alterations unique to pregnancy.
- Discuss the diagnosis and management of hypertensive disorders of pregnancy.
- Identify clinical manifestations and treatment of HELLP syndrome.
- Outline the approaches to managing peripartum cardiomyopathy, thromboembolic disease, and other conditions in pregnancy.
- List priorities for managing the traumatized pregnant patient.

Case Study

A 28-year-old primigravid woman presents at 34 weeks' gestation in labor. She has an elevated blood pressure (BP) of 190/110 mm Hg, heart rate 125 beats/min, and oxygen saturation 86% while on room air. She is in severe respiratory distress, and her chest radiograph shows diffuse bilateral lung infiltrates. You are called to evaluate and manage her deterioration.

– What are the possible diagnoses?

– What immediate interventions are needed?

– What additional diagnostic tests are indicated?

I. INTRODUCTION

A pregnant woman may present for critical care support either with a disease state that is unique to pregnancy or with a critical illness that is not unique to pregnancy. Diseases

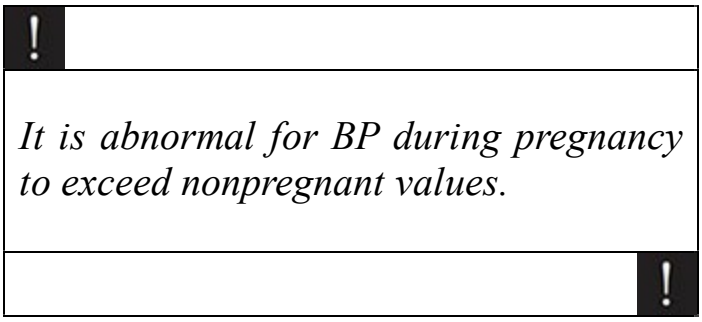
specific to pregnancy include preeclampsia, eclampsia, HELLP syndrome (hemolysis, elevated liver enzymes, and low platelet count), and amniotic fluid embolism syndrome, all of which usually require immediate therapy that may be lifesaving. Some critical illnesses not unique to pregnancy—such as preexisting maternal hypertension, thromboembolic disease, cardiac and respiratory diseases, and trauma—can be unmasked, precipitated, or aggravated by pregnancy. The normal physiologic, metabolic, and hormonal changes of pregnancy may alter the presentation of disease processes and add a level of complexity to diagnosis and treatment. Understanding the normal physiologic changes during pregnancy, delivery, and the postpartum period is the key to managing critically ill obstetric patients with underlying medical diseases and pregnancy-related complications. The most common critical illnesses in obstetric patients are hypertensive disorders and hemorrhage.

II. PHYSIOLOGIC ALTERATIONS

A. Cardiovascular Alterations

Alterations in blood volume and cardiovascular status are among the most dramatic changes that occur in pregnancy. These are adaptive mechanisms that accommodate the increased metabolic needs of both the mother and the fetus during pregnancy, labor, and delivery. Blood volume increases in each trimester, reaching 40% to 50% above normal values by the end of gestation. Cardiac output also increases up to 50% above pre-pregnancy values by the 24th week of gestation and remains elevated until the immediate postpartum period. This is primarily a result of increased stroke volume during the first and second trimesters and increases in heart rate (15 to 20 beats/min) during the third trimester until term. Improved myocardial contractility may account in part for the increase in cardiac output. A significant decrease of 25% to 30% in this output may occur if the patient is placed in the supine position; this causes the gravid uterus to compress the aorta and inferior vena cava, increasing afterload and restricting venous return to the heart. The left lateral decubitus position is the preferred position for pregnant women with serious illness, particularly as gestation progresses and the gravid uterus increases in size. The decrease in cardiac output in the supine position is exaggerated in women with poorly developed venous collaterals who exhibit significant hypotension and bradycardia; this is known as the supine hypotensive syndrome of pregnancy. Filling pressures, such as the central venous and pulmonary artery pressures, typically do not change during pregnancy. A decrease in BP is seen in the second trimester as a result of diminished systemic vascular resistance secondary to the vasodilating effects of progesterone. Peak reduction in BP occurs between 24 and 26

weeks when systolic pressures are reduced by 5 to 10 mm Hg and diastolic pressures by 10 to 15 mm Hg. By term, the BP returns to pre-pregnancy values. Venous flow in the legs is delayed in pregnancy, and this slower velocity of blood return can contribute to occlusion of the pelvic veins and inferior vena cava by the enlarged uterus. This venous stasis also contributes to the common finding of dependent edema and development of varicose veins in the legs and vulva, as well as hemorrhoids. This venous stasis can put patients at risk for deep-vein thrombosis.



Another normal cardiovascular change of pregnancy that may cause or exacerbate illness is remodeling of the heart with enlargement of all four chambers. In particular, left atrial enlargement may precipitate supraventricular and atrial arrhythmias. Systolic ejection murmurs and a third heart sound are commonly detected during pregnancy, but diastolic, pansystolic, and late systolic murmurs suggest a more serious underlying cardiac disorder.

In addition to chamber enlargement, the heart is rotated upward and to the left as the uterus enlarges and the diaphragm is pushed superiorly. This displacement can be seen as cardiomegaly and increased vascular markings on the chest radiograph, although the changes have no clinical significance if the patient has no other evidence of cardiac disease.

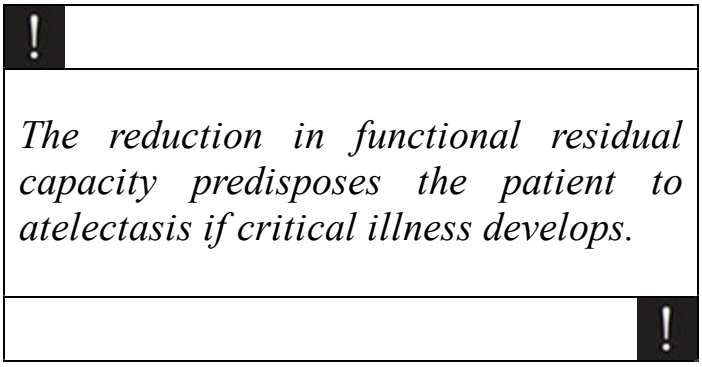
Healthy pregnant women tolerate the cardiovascular and hemodynamic effects associated with pregnancy, as do patients with mild to moderate cardiac disease; however, the incidence of heart failure and arrhythmias is higher in pregnant patients with cardiac disease. Concurrent hemodynamic and fetal monitoring is often necessary for pregnant patients with New York Heart Association (NYHA) functional class III or class IV heart disease.

B. Pulmonary Alterations

The pregnant woman is considered to have a “difficult airway” complicated by edema of the upper respiratory tract as a result of increased blood volume and hormone-induced mucosal edema and hypervascularity. Pulmonary changes in pregnancy include

an increase in tidal volume of approximately 40%, a decrease in functional residual capacity of 20% to 30% or 400 to 700 mL
during pregnancy, and an increase in oxygen consumption by 20% as a result of the rising metabolic needs of the mother and the fetus. Total lung capacity remains unchanged or decreases by less than 5% at term. During pregnancy, metabolic demands can be elevated up to 32% above nonpregnant values by term. The increases in metabolic demands are due to the expanding uterine mass and the size of the fetus, but only 4% is attributed to maternal metabolic demands. The combination of decreased functional residual capacity and increased oxygen consumption during pregnancy diminishes maternal oxygen reserves and subsequently increases the hypoxic risk to both the mother and the fetus in the event of maternal hypoventilation or apnea.

Oxygen requirements rise by approximately 30 to 40 mL/min (15% to 20%) in pregnancy and are met by an increase in minute ventilation, primarily as a result of an expanded tidal volume. The increase in minute ventilation results in a mild compensated respiratory alkalosis with a change in the $Paco_2$ to 26 to 34 mm Hg (3.5 to 4.5 kPa). The pH does not change due to renal compensation, which results in a decrease in serum bicarbonate concentration. Pregnant women who present with a "normal" $Paco_2$ level of 35 to 40 mm Hg (4.7 to 5.3 kPa) should prompt the clinician to look for a cause of impending ventilatory failure.



C. Gastrointestinal Alterations

Hormonal and anatomic changes in pregnancy affect the gastrointestinal tract. Starting at the end of the first trimester, a reduction in lower esophageal sphincter tone caused by high progesterone levels contributes to an increased risk for aspiration. Gastroesophageal reflux and decreased gastric emptying are also present during pregnancy. Alterations in gastric motor function may cause nausea, vomiting, and dyspepsia.

D. Hematologic Alterations

The 40% to 60% increase in plasma volume that occurs by the third trimester is associated with a gain in red cell mass of only 25% at term. The disproportionate rise in plasma volume results in dilutional anemia (physiologic anemia of pregnancy). Hemoglobin concentration is ~11 g/dL (110 g/L) at 24 weeks, when it stabilizes; however, it may increase slightly later in the pregnancy, when there is less discrepancy between the increases in blood volume and red cell mass. The white blood cell count climbs to 10,000 cells/μL (10.0×10^9/L) at term, with a slight reduction in platelet count. Plasma concentrations of all clotting factors except XI, XIII, and antithrombin III increase in pregnancy. Fibrinogen levels may be as high as 600 mg/dL (6.0 g/L) at term. Fibrinogen levels <150 mg/dL (<1.5 g/L) are considered abnormal. Although coagulation test results and bleeding times do not change, these compositional changes result in a hypercoagulable state that, in association with venous stasis and vessel wall trauma, raises the risk for thromboembolic disease. Increased coagulation factors, fibrin generation, inhibited fibrinolysis, and venous stasis contribute to the hypercoagulable state of pregnancy.

E. Metabolic Alterations

Creatinine levels are lower in pregnancy as a result of a rise in the glomerular filtration rate due to increased blood flow to the kidneys. Corticotropin and cortisol levels are increased during pregnancy, with an enlargement of the pituitary gland resulting in a greater risk of postpartum infarction (Sheehan syndrome) if significant blood loss occurs. Occult adrenal insufficiency can result in adrenal crisis from the stress of labor and delivery.

III. HYPERTENSIVE DISORDERS

Hypertensive disorders complicate between 5% and 10% of all pregnancies. Of these disorders, preeclampsia, either alone or superimposed on chronic hypertension, is the most life-threatening condition. Women with a preexisting history of diabetes mellitus, renal disease, or vascular disease, or with a family history of hypertension are more predisposed to developing hypertension during pregnancy.

Hypertension is defined as either a systolic BP of 140 mm Hg or greater, a diastolic of 90 mm Hg or greater, or both. Hypertension is considered mild until blood pressures reach or exceed a systolic BP of 160 mm Hg or a diastolic of 110 mm Hg.

A. Diagnosis of Hypertensive Disorders

1. Gestational Hypertension

Gestational hypertension is defined as hypertension without the presence of proteinuria. It usually manifests as diastolic hypertension that resolves by 12 weeks postpartum, although many women will later develop chronic hypertension. A relatively high rate of recurrence of diastolic hypertension occurs with subsequent pregnancies.

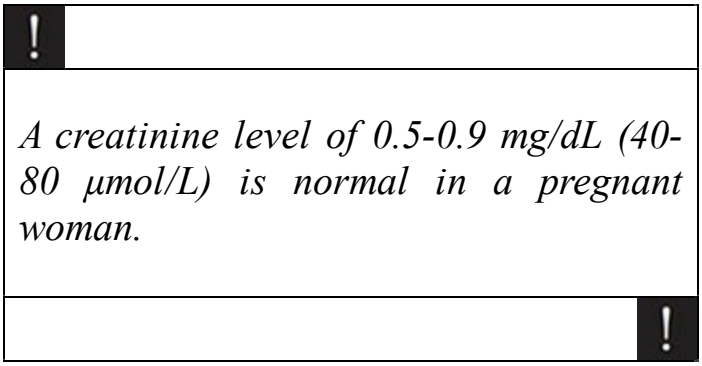
2. Chronic Hypertension with Superimposed Preeclampsia

Chronic hypertension is defined as hypertension before conception or detected before 20 weeks' gestation. When preeclampsia complicates a known hypertensive patient, it is considered chronic hypertension with superimposed preeclampsia. When preeclampsia complicates chronic hypertension, the maternal and fetal prognoses are worse than either condition alone.

Echocardiography can reveal left ventricular hypertrophy, which suggests chronic disease. Other causes of hypertension that are not related to pregnancy, such as renal artery stenosis, pheochromocytoma, and Cushing syndrome, may need to be considered.

3. Preeclampsia-Eclampsia

Preeclampsia is a multisystem disease that usually occurs after 20 weeks, most often near term. It is the most common form of hypertension that complicates pregnancy. It is classically defined as new onset hypertension plus new onset proteinuria; however, some women may present with new onset hypertension with other multiorgan involvement, without proteinuria. Severe symptoms concerning for multisystem involvement include thrombocytopenia (platelet count <100,000/μL), impaired liver function, new onset renal failure (creatinine >1.1 mg/dL or doubling of previous value), pulmonary edema, or new onset cerebral or visual disturbances.



Proteinuria is defined as the excretion of >300 mg of protein in a 24-hour urine

collection or protein/creatinine ratio of at least 0.3. A urine dipstick reading of 1+ can also be used only if no other quantitative methods are available.

Eclampsia is the convulsive phase of preeclampsia, with generalized tonic-clonic seizures. It is the more severe manifestation of the disease. Although seizures are its most dramatic manifestation, other intracranial catastrophes, such as hemorrhage, stroke, or intracranial hypertension, are more likely to cause death.

4. Postpartum Hypertension

Preeclampsia with and without severe features can manifest in the postpartum period. Blood pressures can remain elevated and labile from 2 weeks to 6 months postpartum.

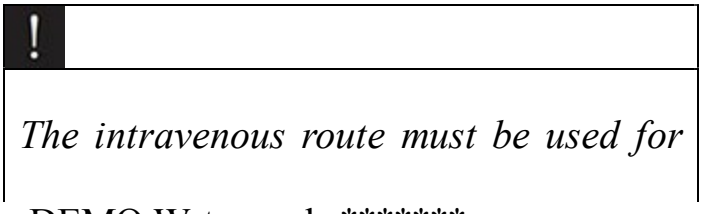
B. Management of Hypertensive Disorders

1. General Guidelines

Patients with eclampsia or severe preeclampsia require hospital admission. Administration of magnesium sulfate for the prevention of seizures, judicious control of BP, and maternal and fetal monitoring should be initiated early. Issues such as ICU admission, management, and delivery of the fetus should be discussed with an obstetrician and the critical care physician as soon as possible. Preventing maternal injury, ensuring maternal and fetal oxygenation, and initiating seizure prophylaxis are the most important aspects of therapy. The treatment of choice in severe preeclampsia is delivery, but fetal maturity must be considered. In most cases of severe preeclampsia that occur after 32 weeks' gestation, delivery is indicated. Consultation with a maternal-fetal medicine specialist is recommended.

2. Seizure Prophylaxis

Intravenous magnesium sulfate is used prophylactically to prevent seizures in preeclampsia with severe features. Magnesium sulfate therapy should be initiated in patients with severe features or symptoms considered premonitory to seizures, such as headache, altered mental status, blurred vision, scotomata, clonus, and right upper quadrant abdominal pain. Magnesium sulfate therapy should also be initiated with the appearance of any signs of progression from mild preeclampsia to severe disease.



The intravenous route must be used for

prophylactic or therapeutic administration of magnesium sulfate for preeclampsia or eclampsia.

Women treated with magnesium sulfate to prevent or treat eclamptic seizures should receive an intravenous loading dose of 4 to 6 g, followed by a maintenance dose of 1 to 2 g/h continued for at least 24 hours.

Magnesium levels are checked 2 to 4 hours later and should be in the range of 2.0 to 3.5 mmol/L (4-7 mEq/L). Maternal respiratory rate, deep tendon reflexes, level of consciousness, and urine output are monitored regularly and correlate well with serum magnesium levels. Respiratory depression, somnolence, or loss of patellar reflexes suggests magnesium levels in excess of the therapeutic range (>3.5 mmol/L or 7 mEq/L). Because magnesium is excreted renally, the infusion rate should be decreased if urine output drops. The maintenance infusion should also be decreased or withheld on the basis of the serum creatinine level. The antidote for magnesium toxicity is 1 g of calcium chloride (10 mL of 10% solution) given intravenously over several minutes.

3. Blood Pressure Control

The goal of antihypertensive therapy is prevention of maternal complications such as stroke, intracranial hemorrhage, acute myocardial infarction, or acute heart failure. There are no convincing data to determine the optimal blood pressure at which antihypertensive medications should be initiated, but sustained systolic BP of at least 160 mm Hg or diastolic BP of at least 110 mm Hg should be treated. Admission to the hospital for acute antihypertensive therapy is recommended for marked elevations in BP or if the patient has end-organ involvement. Intravenous therapy is the standard method of delivering antihypertensive agents for life-threatening conditions.

Angiotensin-converting enzyme inhibitors are contraindicated in pregnancy because of associated fetal and neonatal complications.

Hydralazine, labetalol, or oral nifedipine can be used to treat acute severe hypertension in pregnancy. The drug choice and route of administration should be based on the provider's comfort and experience.

- Parenteral hydralazine (5 mg administered as a slow intravenous push every 15-20 minutes)
- Labetalol (20 mg intravenously initially, and titrated every 10-15 minutes). If the initial 20-mg dose of labetalol is not effective, 40 mg should be given. If the 40-mg dose does not lower the BP to the desired level, it should be followed by an 80-mg dose up to a maximum dose of 300 mg.
- Precipitous drops in BP can occur with aggressive antihypertensive therapy, particularly in the volume-depleted preeclamptic patient. Diuretics should be avoided because most preeclamptic patients have a significantly decreased plasma volume.

4. Supportive Measures

Cardiogenic and non-cardiogenic pulmonary edema often occur during severe preeclampsia. Treatment includes supplemental oxygen to maintain maternal Pa_{O_2} >70 mm Hg (>9.3 kPa) or oxygen saturation ≥94% to prevent fetal hypoxia. The indications for tracheal intubation and mechanical ventilation are the same as those for the nonpregnant patient. Because of increased maternal oxygen consumption and a decrease in the functional lung surface area, the mother is at greater risk for hypoventilation and apnea. Intubation should be approached cautiously in the pregnant woman due to the potential for hypoxemia during induction, the increased risk of aspiration, and the possibility of oropharyngeal edema. Usually, small endotracheal tubes (6.5 or 7.0 mm) are necessary. A pregnant woman who requires intubation should be approached as a full-stomach intubation. Ventilation with a bag-mask device and intubation should proceed with cricoid pressure throughout the procedure to mitigate the increased risk of aspiration. Because preeclamptic and eclamptic patients frequently have intravascular volume depletion, invasive hemodynamic monitoring may be required to optimize management of pulmonary edema. Central venous pressure values have not been shown to correlate with pulmonary artery filling pressures during pregnancy but may guide volume resuscitation. Noninvasive techniques such as echocardiography may be used to assess cardiac output, volume status, and ejection fraction. Vasoconstriction of the renal vasculature in severe preeclampsia frequently leads to oliguria. Intravenous fluid challenges should be instituted cautiously. The empiric use of diuretics without invasive hemodynamic monitoring of intravascular volume is discouraged. Most preeclamptic women with oliguria will respond to 1 to 2 L of crystalloid without the need for

invasive monitoring. The patient's failure to respond to repeated fluid challenges, or the presence of cardiac or respiratory failure, should prompt consideration of hemodynamic monitoring and critical care consultation. Vasodilator therapy may be beneficial if intravascular volume is adequate.

5. Monitoring

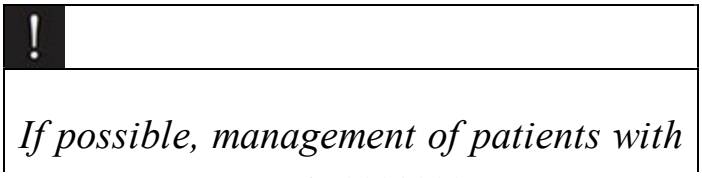
All patients should have their blood pressure monitored regularly, and those who are hypertensive require more frequent assessment. When magnesium sulfate is used, monitoring should include checking patellar reflexes, respiratory rate, and periodic magnesium levels. Invasive hemodynamic monitoring is not usually required in preeclamptic patients, although it is recommended for those with significant cardiac, respiratory, or renal abnormalities.

IV. HELLP SYNDROME

HELLP syndrome is a life-threatening condition that can occur during pregnancy or in the immediate postpartum period. Seen in 4% to 12% of preeclamptic patients, the syndrome is characterized by the following:

- Hemolysis: hemolytic microangiopathic anemia with an abnormal result on peripheral smear, a total bilirubin level >1.2 mg/dL (21 μmol/L), or serum lactate dehydrogenase level >600 U/L
- Elevated liver enzymes: aspartate aminotransferase value >70 U/L or lactate dehydrogenase level >600 U/L
- Low platelet count: <150,000/μL

Variations of the syndrome do not necessarily include all of these manifestations. Patients can present with a variety of nonspecific clinical signs and symptoms, including epigastric or right upper quadrant pain, bleeding gums or nose, petechiae, malaise, nausea, and vomiting. Most HELLP syndrome cases occur at the gestational age of 27 to 36 weeks. Postpartum presentations occur in 20% of cases, usually within 1 to 2 days after delivery. One-third of patients with HELLP syndrome have no evidence of preeclampsia, showing neither proteinuria or hypertension during the pregnancy.



If possible, management of patients with

HELLP syndrome should occur in a tertiary care facility.

HELLP syndrome can be confused with acute fatty liver of pregnancy, thrombotic thrombocytopenic purpura, or adult hemolytic-uremic syndrome, and it may mimic or mask severe sepsis. Laboratory tests that are helpful in differentiating acute fatty liver and HELLP syndrome are listed in **Table 14-1**. HELLP syndrome almost always indicates a need for urgent delivery because of significantly increased fetal and maternal morbidity and mortality rates.

Table 14-1 Laboratory Findings in Acute Fatty Liver, HELLP Syndrome, and Eclampsia/Preeclampsia

Test	Acute Fatty Liver	HELLP	Eclampsia/Preeclampsia
Fibrinogen	↓	Normal or ↑	Normal or ↑
Glucose	↓	Normal	Normal
Ammonia	↑	Normal	Normal
ALT (usual range)	300 U/L	150 U/L	60 U/L
Bilirubin	↑	Normal, mild ↑	Normal, mild ↑
DIC	75%	20%-40%	Rare

Abbreviations: HELLP syndrome, hemolysis, elevated liver enzymes, and low platelet count ALT, alanine aminotransferase; DIC, disseminated intravascular coagulation

Treatment of HELLP syndrome includes supportive care, intravenous magnesium sulfate, and antihypertensive therapy (see section, Hypertensive Disorders). Patients complaining of persistent, severe, or worsening epigastric or right upper quadrant pain should be carefully examined for spontaneous fracture or rupture of the liver. Computed tomography or magnetic resonance imaging can be useful in diagnosing intrahepatic bleeding. Other complications of HELLP syndrome may include intracerebral hemorrhage, acute renal failure, and fulminant hepatic failure.

V. POSTPARTUM HEMORRHAGE

While there is no single suitable definition for postpartum hemorrhage, it is classically defined as an estimated blood loss in excess of 500 mL following a vaginal birth or a loss of greater than 1,000 mL following cesarean delivery. Postpartum hemorrhage generally is classified as primary or secondary, with primary hemorrhage occurring

within the first 24 hours of delivery and secondary hemorrhage occurring between 24 hours and 6 to 12 weeks postpartum. Primary postpartum hemorrhage is caused by uterine atony in the majority of cases. Etiologies for primary and secondary postpartum hemorrhage include overdistension of the uterus, retained placental products, coagulation defects, and uterine inversion.

Since uterine atony is the most common cause of postpartum hemorrhage, the diagnosis is made clinically by palpation of a large and boggy uterus. The second most frequent cause of primary postpartum hemorrhage is lacerations of the lower genital tract that occur spontaneously or as a result of traumatic labor. Hematomas resulting from these lacerations can also lead to significant blood loss at the time of delivery, specifically if the hematoma is progressively enlarging.

Ongoing blood loss from uterine atony requires the administration of additional uterotonics as the first-line treatment for hemorrhage (**Table 14-2**).

Table 14-2 Medical Management of Postpartum Hemorrhage[a]

Drug*	Dose/Route	Frequency	Comment
Oxytocin	IV: 10-40 units in 1 L normal saline or lactated Ringer solution IM: 10 units	Continuous	Avoid undiluted rapid IV infusion, which causes hypotension.
Methylergonovine	IM: 0.2 mg	Every 2-4 h	Avoid if patient is hypertensive.
15-methyl prostaglandin $F_{2\alpha}$	IM: 0.25 mg	Every 15-90 min, 8 doses maximum	Avoid in asthmatic patients; relative contraindication if hepatic, renal, and cardiac disease present. Diarrhea, fever, tachycardia can occur.
Dinoprostone	Suppository: vaginal or rectal, 20 mg	Every 2 h	Avoid if patient is hypotensive. Fever is common. Stored frozen, it must be thawed to room temperature.
Misoprostol (prostaglandin E_1)	800–1,000 µg rectally		

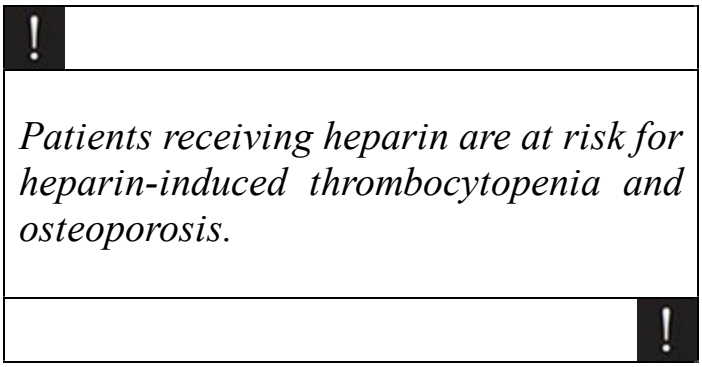
Abbreviations: IV, intravenously; IM, intramuscularly
*All agents can cause nausea and vomiting.
[a]Modified from Dildy GA, Clark SL. Postpartum hemorrhage. *Contemp Ob/Gyn*. 1993;38(8):21-29.

General treatment measures include aggressive and early fluid resuscitation and attempts to locate the source of the bleeding. Maternal mortality rates increase when treatment is delayed and blood loss is underestimated. Patients with ongoing blood loss resulting in hemodynamic instability require packed red blood cell transfusions in

addition to fluid administration. Depending upon the amount of blood loss and the presence of coagulopathy, additional blood products including fresh frozen plasma, platelets, and cryoprecipitate may be needed. Angiographic embolization and surgical interventions, including hysterectomy, may be required for severe uterine hemorrhage unresponsive to uterotonic drug therapy.

VI. THROMBOEMBOLIC DISEASE

The incidence of thromboembolic disease in pregnant women during the immediate postpartum period is five times that in nonpregnant women. Risk increases with rising parity, cesarean delivery, operative vaginal delivery, previous deep venous thrombosis, and increased maternal age.



Patients receiving heparin are at risk for heparin-induced thrombocytopenia and osteoporosis.

Although manifestations of pulmonary embolism in pregnant women are similar to those in nonpregnant women (**Chapter 13**), the physiologic changes of pregnancy complicate evaluation. Lower-extremity edema, leg pain, and dyspnea are common in pregnancy and create a diagnostic dilemma for the clinician. If a chest radiograph is obtained to rule out other pulmonary problems, such as pneumonia, the fetus must be shielded. After 16 weeks' gestation, D-dimer values are elevated above the usual normal range and are of little diagnostic utility. Doppler scanning of the lower extremities (compression ultrasound), when available, is usually the first diagnostic test for deep vein thrombosis in pregnancy, but it is less accurate for calf and isolated iliac vein thrombosis. For diagnosing pulmonary embolism, ventilation/perfusion scanning is reliable in a pregnant woman, and it may be beneficial to perform perfusion scanning alone initially. If there are no perfusion defects, the scan can be considered negative. Computed tomography angiography (CTA) is an alternative method which is more sensitive for emboli in the central arteries and less sensitive for subsegmental emboli. The teratogenic and oncogenic risks to the fetus from these diagnostic tests are not significant, and the potential for maternal death from undiagnosed thromboembolic disease outweighs the risk of radiation exposure. An appropriate diagnostic evaluation should always be

performed when indicated. Heparin therapy should be initiated immediately when the diagnosis of pulmonary embolism is suspected and should be continued if the diagnosis is confirmed.

The treatment of stable pulmonary embolism in the pregnant patient parallels that in the nonpregnant patient, except that warfarin is relatively contraindicated in pregnancy and absolutely contraindicated during the first trimester, when the risk of teratogenicity is greatest. Instead, unfractionated heparin can be administered intravenously using a weight-adjusted dose regimen to achieve an activated partial thromboplastin time of 1.5 to 2.5 times control. Treatment is then converted to subcutaneous administration, starting at 5,000 IU of unfractionated heparin every 12 hours and aiming for the same activated partial thromboplastin time measured 6 hours after administration. Low-molecular-weight heparin or dalteparin/tinzaparin is safe for the fetus and can be used for the treatment of thromboembolic disease. The use of low-molecular-weight heparins may be preferred given the potential for fewer adverse events, more predictable therapeutic response, and easier dosing schedules. After delivery, warfarin can be substituted for 3 to 6 months of total therapy, depending upon risk factors.

When considering regional anesthesia for labor pain, intrapartum management requires that therapeutically dosed unfractionated heparin be discontinued at least 6 hours before epidural or spinal anesthesia and prophylactically dosed low-molecular-weight heparin be discontinued 12 hours prior to regional anesthesia. Therapeutically dosed low-molecular-weight heparin should be held 24 hours before regional anesthesia. Postpartum therapeutic and prophylactic heparin usually can be resumed at least 1 hour after the epidural catheter is removed or spinal needle is placed. Prophylactic low-molecular-weight heparin can be resumed after 4 hours, and therapeutic low-molecular-weight heparin can be started after 24 hours. The risks with intrapartum use include a significantly increased likelihood of hemorrhage with cesarean delivery, bleeding and hematoma formation if a regional or epidural anesthetic is used, and increased bleeding if an episiotomy or operative vaginal delivery is performed. Patients with massive pulmonary embolism and/or hemodynamic instability should be managed much like nonpregnant patients, with careful consideration of risks (**Chapter 13**).

VII. PERIPARTUM CARDIOMYOPATHY

A. Clinical Manifestations

Peripartum cardiomyopathy is defined as left ventricular systolic dysfunction that occurs

during the last month of pregnancy or within 5 months postpartum, in the absence of identifiable cause for the cardiac failure and absence of prior heart disease. Clinical symptoms include severe progressive dyspnea, progressive orthopnea, paroxysmal nocturnal dyspnea, and syncope with exertion. Signs include evidence of right and left heart failure, generalized or chamber-specific cardiomegaly seen on a chest radiograph, evidence of pulmonary hypertension, murmurs, prominent jugular vein distension, cyanosis, clubbing, or dysrhythmias. Most patients present with dramatic symptoms soon after delivery. Peripartum cardiomyopathy is associated with maternal age >30 years, first pregnancy, twin pregnancies, preeclampsia, and pregnant women who receive tocolytic agents. The course tends to be more severe in older patients of higher parity with later onset of symptoms after delivery. Approximately 50% of women suffering from peripartum cardiomyopathy recover baseline ventricular function within 6 months of delivery, but in those with persistent cardiac failure, the mortality rate approaches 85% over 5 years.

B. Management

Initial evaluation of the patient with possible peripartum cardiomyopathy includes a chest radiograph, electrocardiogram, and echocardiogram. Initial therapy includes bed rest, sodium restriction, diuretics, and possibly vasodilators. Patients who present with pulmonary edema and cardiac decompensation often require invasive hemodynamic monitoring for careful and judicious fluid management, intravenous inotropic support, and afterload reduction. Useful drugs include digoxin, dobutamine, and milrinone as inotropic agents and angiotensin-converting enzyme inhibitors for afterload reduction, although the latter are contraindicated before delivery. Loop diuretics can help with symptomatic relief of systemic and pulmonary congestion, but should be used cautiously in the last month of gestation due to their effect on uteroplacental perfusion. If symptoms develop in the antepartum period, consultation with the obstetrician, critical care physician, and anesthesiologist can guide decisions regarding early delivery. Early delivery is not usually recommended because many patients experience worsening of symptoms postpartum. Urgent delivery may be considered in pregnant women with advanced heart failure or hemodynamic instability. Critically ill patients who require inotropic and mechanical support should undergo cesarean delivery. Anticoagulation should be considered in peripartum cardiomyopathy, enlarged cardiac chambers, ejection fraction <35%, and atrial fibrillation as systemic and pulmonary emboli are significantly more common than in other cardiomyopathies. Right and left ventricular-assist devices can serve as a bridge for patients who may eventually recover or who require cardiac transplantation as the definitive treatment because of failure of pharmacologic therapy. Subsequent pregnancies are discouraged in women who have no

resolution of the signs and symptoms of heart failure 6 months after delivery.

VIII. SEVERE ASTHMA

Patients with severe asthma who require intubation and mechanical ventilation should have the minute ventilation adjusted to avoid hyperventilation and respiratory alkalosis. An alkalotic pH may lead to reduction of uteroplacental blood flow, impairing fetal oxygenation. Occasionally, life-threatening asthma can be refractory despite mechanical ventilation and intensive medical therapy; in such cases, cesarean delivery should be considered.

IX. AMNIOTIC FLUID EMBOLISM

Amniotic fluid embolism, a catastrophic event with significant morbidity and mortality rates, may be associated with miscarriages, abortions, and amniocentesis. It occurs most often during labor and delivery or immediately postpartum. The presentation includes typical findings of hypoxia, shock, altered mental status, and disseminated intravascular coagulation; seizure activity, agitation, fetal distress, fever, chills, nausea, and vomiting may also be present. The diagnosis of amniotic fluid embolism is clinical and a diagnosis of exclusion. It should be considered in pregnant or postpartum women who abruptly and dramatically present with profound shock and cardiovascular collapse associated with severe respiratory distress. Occasionally, disseminated intravascular coagulation is the first presenting sign. Other life-threatening conditions, such as pulmonary embolism, sepsis, air embolism, eclampsia, and myocardial infarction, should be excluded. Radiographic evidence of pulmonary edema with bilateral interstitial and alveolar infiltrates is possible. Management is supportive and focuses on rapid maternal cardiopulmonary stabilization and prevention of subsequent end-organ damage.

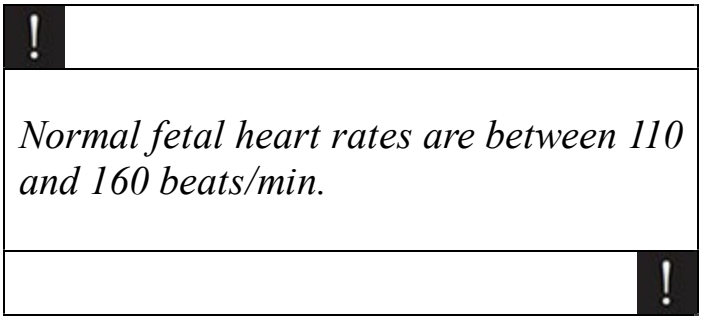
X. TRAUMA IN PREGNANCY

Treatment priorities for the pregnant patient with traumatic injury are the same as those for nonpregnant patients (**Chapter 9**). There are, however, unique changes that should be taken into account during clinical assessment. The gravid uterus complicates the initial abdominal assessment. The height of the uterus is roughly at the symphysis pubis at 12 weeks and the umbilicus at 20 weeks; thereafter, the height increases by 1 cm each

week up to 36 to 40 weeks, when the uterus encompasses almost the entire abdomen. Late in pregnancy, a widened symphysis pubis and widened sacroiliac joints are possible. All pregnant patients with major traumatic injuries should be admitted to a facility with surgical obstetric capabilities. When evaluating the patient's mental status, clinicians should be aware that neurologic symptoms of eclampsia may mimic head injury. Aortocaval compression in the supine position can contribute to hypotension by restricting blood return to the heart. Whenever possible, the patient should be placed in the left lateral decubitus position; at a minimum, the right hip can be raised by 4 to 8 cm to displace the uterus away from the inferior vena cava. If any question of spinal injury exists, spinal alignment should be maintained and the patient logrolled.

The pregnant patient can lose up to 35% of blood volume before significant tachycardia, hypotension, and other signs of hypovolemia are seen. Therefore, the fetus may actually be in a state of hypoperfusion while the mother's condition seems stable. An assessment of the fetal heart rate is an essential part of the initial survey and can be accomplished easily with a fetoscope or a Doppler fetoscope. A conventional stethoscope can be used to auscultate the fetal heart rate in the third trimester, although it may be difficult to differentiate between maternal and fetal heart tones if the mother is tachycardic. If available, ultrasonography is effective for documenting fetal cardiac activity and function. Late or persistent decelerations of the fetal heart rate are an ominous sign. If the fetus cannot be examined adequately at the facility, the patient should be stabilized and transported as soon as possible to another facility with the capability for fetal examination and monitoring. A minimum of 4 hours of fetal monitoring is necessary after trauma.

Secondary assessment should evaluate uterine irritability or contractions, fetal heart rate, and fetal movement. A pelvic examination should be performed if necessary. If there is any question of vaginal bleeding, a sterile speculum examination should be performed by a qualified, experienced caregiver, preferably following a sonographic examination to exclude placenta previa. A manual vaginal examination is contraindicated if placenta previa is being considered.



Definitive care of the pregnant trauma patient includes adequate hemodynamic and

respiratory resuscitation, stabilization of the mother, continued fetal monitoring, and radiographic studies as necessary, in addition to obstetric care, critical care, and surgical consultation. If the mother is Rh-negative, Rh_o(D) immune globulin should be given within 72 hours of injury, even when trauma is minimal. An assessment of the amount of fetal red blood cells in the maternal circulation by means of a Kleihauer-Betke stain is advised. Obstetrical consultation for the appropriate dosage of Rh_o(D) immune globulin is recommended.

XI. SEPTIC PELVIC THROMBOPHLEBITIS

Septic pelvic thrombophlebitis, characterized by infected clot(s) in the pelvic veins, can occur in the antepartum period, after vaginal and cesarean deliveries, as well as after both spontaneous and therapeutic abortions. Physical findings are nonspecific. Fever that fails to respond to empiric antibiotics in a postpartum patient should prompt consideration of septic pelvic thrombophlebitis. Evidence of systemic septic emboli from sepsis, metastatic abscesses, and septic pulmonary emboli may be present. Ultrasonography or computed tomography studies are not diagnostic but occasionally may show evidence of a clot. Because this is a diagnosis of exclusion, patients are typically treated on the basis of clinical suspicion. Women with septic thrombophlebitis usually have symptomatic improvement with antimicrobial treatment, and studies have shown that the addition of anticoagulation to antimicrobial therapy has not proven to be beneficial.

XII. MECHANICAL VENTILATION DURING PREGNANCY

The indications for intubation and mechanical ventilation in pregnant patients are the same as those for nonpregnant patients. The maternal oxygen reserve is decreased and significant arterial desaturation occurs if the patient is hypoventilating or apneic for even a short time. Such episodes increase the hypoxic risk to the fetus as well. Mechanical ventilator parameters should be adjusted to maintain the $Paco_2$ in the range of 30 to 32 mm Hg (4.0-4.3 kPa). Data about permissive hypercapnic ventilation in the pregnant patient are limited, although chronic elevations of maternal Pco_2 up to 60 mm Hg (8.0 kPa) in those with congenital heart diseases have not been shown to be detrimental to the fetus. Caution should be used when considering noninvasive ventilation due to the increased risk of aspiration during pregnancy.

Expeditious delivery in the patient requiring mechanical ventilation during pregnancy is

indicated only with evidence of placental disruption, disseminated intravascular coagulation, chorioamnionitis, or severe preeclampsia. It may also be indicated for patients with stiff, noncompliant lungs requiring high peak airway pressures or pressure control ventilation. Delivery while the mother is receiving mechanical ventilation may improve diaphragmatic excursion and decrease elevated airway pressures. Successful spontaneous delivery is possible during mechanical ventilation.

XIII. ADVANCED LIFE SUPPORT IN PREGNANCY

When cardiac arrest occurs in a pregnant woman, standard advanced life support resuscitative methods can and should be undertaken. With advanced gestation or a large uterus, a wedge should be placed under the right flank to displace the uterine contents to the left, improving venous return to the heart. Alternatively, the uterus can be displaced manually to the left. Chest compressions are performed slightly above the center of the sternum to account for elevation of the diaphragm. If initial attempts with standard advanced cardiac life support resuscitative measures are unsuccessful and the gestational age and size are estimated to be ≥24 weeks, then a decision to perform a perimortem cesarean delivery should be made rapidly so that it is accomplished within 4 to 5 minutes of arrest. This option is applicable only when the uterus is deemed large enough to impede life support efforts by significant aortocaval compression, which further worsens maternal hemodynamics. The principal reason for performing a perimortem delivery is to improve cardiac output by augmenting venous return to the heart with effective cardiac compressions. Standard medications for cardiopulmonary resuscitation should be used. Obstetric and neonatology assistance should be sought if possible.

XIV. PHARMACOTHERAPY

Choice of medications for the pregnant woman must take into account the potential for adverse effects on the fetus (**Table 14-3** and **Table 14-4**). Certain medications, such as warfarin, angiotensin-converting enzyme inhibitors, diazepam, and phenytoin, have known or potential adverse effects and should be avoided when acceptable alternatives are available. In general, the selection of any new medication for a critically ill or injured pregnant patient should include a review of its indications and pharmacology as well as alternative approaches to management. A clinical pharmacist should be consulted to obtain information about fetal risk associated with drug therapy.

Table 14-3 U.S. Food and Drug Administration Categories of Fetal Drug Toxicities

Category	Description
A	Controlled studies in pregnant women have not demonstrated any risk to the fetus in the first trimester. These drugs are considered to be relatively safe for use during pregnancy.
B	No known specific risks are associated with the use of the drug in pregnancy, but controlled human studies are lacking. If adverse effects were shown in animal reproduction studies, they were not confirmed in controlled human trials.
C	Studies in women and animals are not available or studies in animals have revealed adverse effects on the fetus. Most new drugs fall into this category. These drugs should be given only if the potential benefit justifies the potential fetal risk.
D	These drugs have shown a definite fetal risk in controlled human trials. However, their use may be necessary during pregnancy, and a risk-benefit assessment needs to be performed before they are used.
X	These drugs have shown a definite risk to the fetus, and their use is contraindicated because the risks outweigh the potential benefits.

Table 14-4 Toxicity Categories for Selected Drugs During Pregnancy[a]

Antiarrhythmics		**Anticonvulsants**		**Diuretics**	
Amiodarone	D	Carbamazepine	D	Furosemide	C
Lidocaine	B	Magnesium sulfate	B	Spironolactone	C
Procainamide	C	Phenobarbital	D		
		Phenytoin	D	**Neuromuscular Blockers**	
Antibiotics				Cisatracurium	B
Acyclovir	B	**Antihypertensives**		Rocuronium	C
Aminoglycosides		ACE inhibitors		Succinylcholine	C
Ophthalmic gentamicin	C	First trimester	C	Vecuronium	C
		Second, third trimesters	D		
Injectable gentamicin	D			**Sedatives/Analgesics/ Anxiolytics**	
Ophthalmic tobramycin	B	β-Blockers			
		Metoprolol	C	Benzodiazepines	D
Injectable tobramycin	D	Atenolol	D	Codeine	C
		Carvedilol	C	Haloperidol	C
		Labetalol	C	Morphine	C
Amikacin	D	Clonidine	C	Propofol	B
Azithromycin	B	Hydralazine	C		
Cefotetan (avoid)	B			**Steroids**	
Ceftriaxone (avoid)	B	**Cardiovascular Medications**		Dexamethasone	C
Cephalosporins	B	Amrinone/milrinone	C	Hydrocortisone	C
Clindamycin	B	Aspirin	D	Prednisolone	C
Metronidazole	B[b]	Atropine	C		

Penicillins	B	Digoxin	B	**Other**	
Quinolones	C	Dobutamine	C	Aminophylline	C
Sulfonamides	B	Dopamine	C	H_2 blockers	B
Trimethoprim	C	Epinephrine	C	Heparin	C
Vancomycin		Nitroglycerin	C	Insulin	B
PO	B	Nitroprusside	C	Mannitol	C
IV	C	Norepinephrine	C	Warfarins	X
		Thrombolytics	C		
		Vasopressin	C		
		Verapamil	C		

Abbreviations: ACE, angiotensin-converting enzyme; PO, by mouth
[a]Data from Lexi-Comp's Drug Information Handbook, 2011-2012. Hudson, OH: Lexicomp, Inc.; 2011.
[b]Contraindicated in first trimester

Key Points

Critical Care in Pregnancy

- A significant decrease in cardiac output may occur with advanced gestation or a large uterus when the patient is placed in the supine position because the gravid uterus restricts venous return and aortic blood flow.
- The diagnosis of preeclampsia is based on the development of new onset hypertension with proteinuria after 20 weeks' gestation or severe features indicating multisystem involvement.
- Eclampsia is defined as preeclampsia with generalized tonic-clonic seizures.
- Magnesium sulfate (20% solution), used as seizure prophylaxis in preeclampsia and as treatment for eclamptic seizures, requires close monitoring.
- Anticoagulation with heparin (unfractionated or low-molecular-weight) is used to treat pulmonary embolism in pregnancy. Warfarin is contraindicated, particularly in the first trimester.
- Treatment of underlying cause, along with early and aggressive treatment with fluid and blood products, is necessary in primary postpartum hemorrhage.
- Priorities for the resuscitation of the pregnant trauma patient are the same as those

for nonpregnant patients.

- The pregnant woman can lose up to 35% of her blood volume before tachycardia, hypotension, and other signs of hypovolemia are seen. This can mask significant fetal compromise as well as ongoing maternal blood loss.
- If the mother is Rh-negative, Rho(D) immune globulin should be given, even after minimal truncal trauma.
- Indications for intubation and ventilation are the same for pregnant patients as for nonpregnant patients. Adjust mechanical ventilator settings to maintain the P_{CO_2} level in the range of 30 to 32 mm Hg (4.0-4.3 kPa).
- If initial resuscitative measures are ineffective, a perimortem cesarean delivery should be considered within 4 or 5 minutes of cardiac arrest to improve maternal hemodynamics.
- When choosing medications for the pregnant woman, it is important to take into account their potential adverse effects on the fetus.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

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15. ACOG Committee on Practice Bulletins-Obstetrics. ACOG practice bulletin no. 123. Thromboembolism in pregnancy. *Obstet Gynecol*. 2011;118:718-729.

Suggested Websites

1. American Congress of Obstetricians and Gynecologists. www.acog.org
2. Society of Critical Care Medicine/Guidelines. www.sccm.org

ETHICS IN CRITICAL CARE MEDICINE

Objectives

- Review the ethical principles guiding decision-making in critical care.
- Explore ethical dilemmas that involve withdrawal of life support in critically ill patients, do-not-attempt-resuscitation orders, nonbeneficial and medically futile therapy, and triage.
- Define and recognize the different types of advance directives used to guide care for patients lacking medical decision-making capacity.
- Outline the decision-making process used in medical ethics in the critical care setting.

Case Study

Mrs. Clark, a hospitalized 72-year-old woman who had abdominal wall hernia repair 10 days ago, sustained a cardiac arrest after massive aspiration. Cardiopulmonary resuscitation was initiated. She was found in asystole, but responded to intubation, defibrillation, and epinephrine after some difficulty. She was transferred to the ICU but developed severe acute respiratory distress syndrome. She now is unresponsive to painful stimuli, her pupils are dilated and fixed, and corneal reflexes are absent. She is hemodynamically stabilized with improving respiratory function. She remains in a deep coma.

– Who should make decisions regarding the patient's medical care, and on what basis?

– What are the goals of care for this patient?

– Should further therapy be limited or withdrawn?

– What process should be utilized to address these issues?

– What potential dilemmas might arise in discussions with the patient's family?

I. INTRODUCTION

Ethics is one of the foundations of laws, statutes, and regulations that govern the practice of medicine in many countries. Application of ethical principles may vary in different regions and nations. Ethics is not identical to existing laws; often it is in critical tension with laws, leading to statutory change. Ethics is closely related to morality, culturally accepted norms regarding right and wrong, but it is not reducible to prevailing or conventional values. At its best, ethics may lead to substantive moral reform.

Ethics is the branch of philosophy that deals with the concepts of what is right or wrong conduct and what is good and bad. The basis of medical ethics is rooted in ancient Greek theories of morality. Modern medical ethics has been influenced by the moral theories formulated by Immanuel Kant, Jeremy Bentham, and John Stuart Mill.

Ethics is the critical, reflective consideration of moral practices in light of basic principles of conduct and value. Medical ethics involves critical reflection on practices such as clinical research, resource allocation criteria, relationships between patients and their healthcare providers, and healthcare policy formulation. It is at the heart of the patient-clinician relationship, which is grounded in trust. Healthcare professionals have an obligation to act in their patients' best interests, recognizing an inequality of knowledge, information, and experience. Clinicians possess medical expertise but are limited in their knowledge of patients' goals and values. Shared decision-making is one way of productively engaging these differences to produce what is in the best interest of the patient while preserving the clinician's professional integrity.

In the critical care context, three sets of circumstances typically bring patients at risk of dying in the hospital to the emergency department: (1) an acute event in an otherwise healthy person (such as trauma, stroke, myocardial infarction, or pneumonia); (2) a recurrent or relapsing decompensation in a patient with a chronic and progressive disease (such as respiratory failure in chronic lung disease, pneumonia complicating dementia, heart failure in cardiomyopathy); or (3) the patient's arrival at a critical point in a progressive, unrelenting decline (such as cancer or dementia). Many of these at-risk patients may be admitted to an ICU. Such patients may be unable to participate in decisions about their medical care and depend upon advance directives or surrogate decision-makers to guide the healthcare team regarding treatment.

The critical care team is involved in end-of-life care decision-making in three key

situations: (1) limitation of therapy and/or resuscitation attempts, (2) withdrawal of life support, and (3) triage. Therefore, the critical care team must be able to effectively communicate with patients and their families about prognosis and futility, reasonable goals of therapy, healthcare advance directives, and options for limitation of resuscitation efforts or removal of life support. Without formal discussions, patients' preferences are difficult to predict; assumptions based upon quality of life, age, or functional status may be inaccurate; and physicians' choices may reflect their own preferences rather than those of their patients.

Healthcare providers must be both cognitively and emotionally prepared to communicate among themselves and with patients and families regarding: (1) realistic goals, (2) expectations for treatments and alternatives, (3) patients' expressed and implied desires regarding medical interventions and the implications of those desires, and (4) acceptable therapeutic options. Meaningful discussions of these issues are grounded in a thorough understanding of medical ethics, individual and collective cultural values, and pertinent legal principles. The competency of providers as communicators correlates directly with patients' and families' satisfaction with the medical care provided and also enhances the professional integrity of the providers.

II. THE GUIDING ETHICAL PRINCIPLES OF HEALTHCARE

In healthcare, ethical principles protect patient interests and inform professional integrity. The guiding ethical principles of healthcare are a conceptual framework for providing patient-centered care (care that is appropriately respectful of patients), and for grounding the professional standards of healthcare practice that define excellence. These principles are also helpful in identifying, analyzing, and contributing to the resolution of ethical problems that occur in the practice of medicine. The four commonly accepted ethical principles of healthcare are:

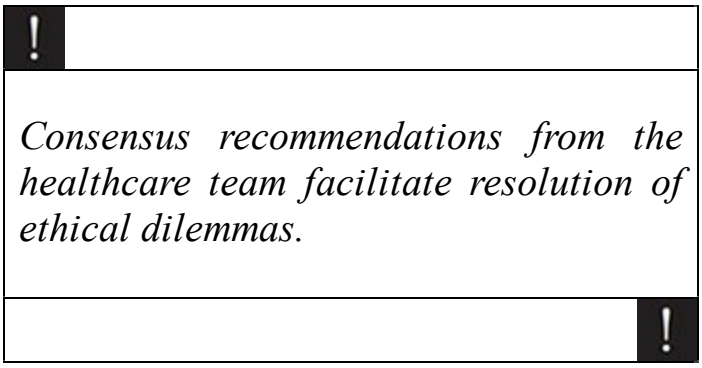
- **Autonomy:** Respect the right of an individual to be self-directing and to make decisions freely and independently; this recognizes the patient's sovereignty over his or her own body.
- **Beneficence:** Act in the best interest of patients and promote their well-being. Different value systems can lead to different concepts of what is best for an individual patient.
- **Nonmaleficence:** *Primum non nocere,* the Latin tenet which translates as "above all else, do no harm." *Harm c*an be defined as the intentional or careless infliction of physical, psychological, or emotional distress through either actions or

omissions.

- **Justice:** Treat all persons fairly and equitably; treat similar cases in the same manner and different cases differently.

III. ETHICAL DILEMMAS IN CRITICAL CARE

Many, if not all, ethical dilemmas can be handled professionally with utmost respect for patient needs and professional integrity when decisions involve consideration of the treatment situation, truthful exchange of information, thorough discussion of the patient's wishes and expectations, understanding of pertinent ethical principles, and coordination among members of the healthcare team. Uncertainty and ambiguity on the part of the physician, critical care team, patient, or family make meaningful discussion and decisions difficult. The team leaders are responsible for ensuring that the healthcare environment is characterized by open communication, caring, and support. In rare situations where some members of the team have conflicting deeply held beliefs, serious emotional conflicts, or conflicts of interest that preclude open and objective communication and decision-making, they may request to be excused and transfer patient care responsibilities to a colleague. Patients and families can sense uncertainty and ambiguity, and are likely to react with suspicion and confusion. A consensus on the goals of care and treatment plan also facilitates consistent communication and documentation and minimizes liability risks. In institutions where ethics consultation teams are available, their involvement has been regarded favorably by most participants.



A. Advance Directives

To make binding decisions such as refusal of recommended medical care or limitation of resuscitation, a person must be legally able to do so. Incompetency is determined by a court and is a judgment that a person lacks the abilities required to give or withhold

informed consent. While competent patients are legally empowered to make decisions, unemancipated minors or mentally impaired individuals may not be competent for decision-making purposes. Distinct from legal competence, the capacity to make decisions refers to the ability to make informed, voluntary decisions in a specific circumstance; because of medications, injuries, or metabolic derangements that impair judgment, a patient may lack capacity. Patients must have both competence and capacity to consent, to refuse, or to limit medical care, as well as to establish advance directives regarding medical care. Their agreement must be obtained without fraud, duress, or coercion after full, reasonable disclosure. The basis, process, and outcome of all discussions leading to such decisions should be carefully documented to supplement any required forms and clinician orders. Unlike consent to treatment, limitation or refusal of treatment is never implied.

An advance directive is an instructional statement that takes effect at some time in the future when specific conditions are met. A capable, competent person can often leave verbal or written instructions directly for healthcare professionals and/or select a surrogate to guide medical decisions. If patients have left unambiguous and detailed instructions regarding their preferences for life-sustaining therapy in the event they become incapacitated, such instructions are usually binding and carried out. However, most patients' instructions are neither sufficiently detailed nor unambiguous for the circumstances of their future illness. The role of the surrogate decision-maker is to inform the healthcare team of what the patient's wishes and values would be under the circumstances; the wishes and values, therefore, are not those of the surrogate but of the patient. The surrogate makes a substituted judgment based on explicit instructions or direct and indirect communication of the patient's preferences and expectations. The following tools may be used to convey a patient's preferences:

- **Advance healthcare directive:** This document contains specific, substantive statements of the patient's values and wishes regarding medical care. It may also specify procedures that the patient wants to receive or forgo in specific circumstances. In most cases, this document also enables the patient to name a healthcare agent who will make decisions for the patient when incapacitated.
- **Durable power of attorney for healthcare:** A durable power of attorney is a proxy directive that assigns one person authority to perform specified actions on behalf of the signer. The power is "durable" because, unlike the usual power of attorney, it continues to be in effect if the signer becomes incompetent.
- **Healthcare proxy:** A proxy is a person appointed by the patient specifically for the purpose of making healthcare decisions on the patient's behalf.

- **Next of kin:** Under some circumstances, in some countries or states, the next of kin are authorized by law to speak on behalf of an incapacitated patient. Surrogacy hierarchies that must be considered in healthcare decision-making are often defined by law. Ethically, the person who knows the patient best is the appropriate surrogate decision-maker. This person may not be the legally identified next of kin.
- The healthcare provider should be certain that the conditions for invoking an advance directive as intended by the patient have occurred before acting upon the directive. Similarly, acquiescing to requests made by surrogates occurs only after consideration of proper medical and ethical decision-making principles. If an incapacitated patient's specific wishes and values are unknown, a surrogate is usually expected to act in the best interests of the patient.

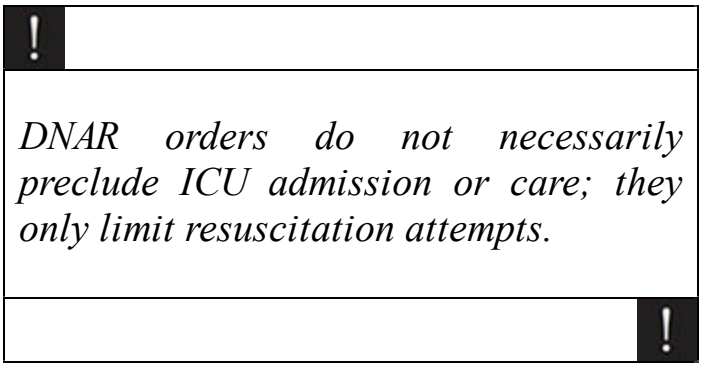
B. End-of-life Care and Termination of Life Support

The goal of end-of-life care is to allow patients to die with dignity and respect and to exercise an element of control over their death. It is paramount that in all communications it is made clear that *care is not being withdrawn*; rather, it is life support or unwanted medical interventions that are withdrawn after the goals of treatment have changed. In many cases, the intensity of care may actually escalate following termination of life support as comfort needs are addressed. "Do not attempt resuscitation" never means "do not treat." Before the removal of life support, a proper do-not-attempt-resuscitation (DNAR) order should be in effect based on local and institutional regulations. A plan for comfort measures should be developed by the healthcare team and must address anxiety and analgesia. Though they may have this effect, comfort care interventions are not intended to directly hasten death; this distinguishes comfort care from euthanasia and physician-assisted suicide.

C. Do-not-attempt-resuscitation Orders

DNAR orders, also known as do-not-resuscitate (DNR) orders, are explicit physician orders restricting specific medical interventions in the event of a cardiopulmonary arrest. Because resuscitation efforts are not always successful, it is more accurate to refer to these as limitations on **attempts** to resuscitate. Such orders are usually based on a patient's expressed or written wishes or on such wishes as they are known to a proxy or surrogate decision-maker. DNAR orders may include categorical specifications that limit blood transfusions, intubation and mechanical ventilation, defibrillation, cardiopulmonary resuscitation in an already mechanically ventilated patient, or an escalation of existing ICU treatment. If such orders are agreed upon, it is usually

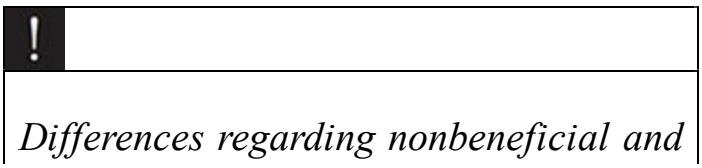
advisable to review all other treatment modalities to determine if they continue to be compatible with the changed goals of care (e.g., dialysis, medically provided fluids and nutrition, antibiotics). Factors that suggest a discriminatory intent must never form the basis for initiating DNAR discussions; these factors include gender, age, race, and economic or social status. Suicidal ideation and treatable depression must be excluded as reasons for a patient's wishes to limit resuscitation or terminate life support.



DNAR orders do not necessarily preclude ICU admission or care; they only limit resuscitation attempts.

D. Medical Futility/nonbeneficial Medical Treatment

Medical futility is a nebulous concept, which is why some prefer the concept of nonbeneficial medical treatment. Both concepts generally refer to medical interventions that are highly unlikely to contribute to a beneficial outcome for the patient. The key problem associated with medical futility or nonbeneficial medical treatment is that it is based on situational value judgments. Interventions perceived as medically futile or nonbeneficial in one institution by some providers at a certain time may not be perceived as such by others at a different time. These concepts are also based on the anticipated outcome in terms of probability of survival, values regarding minimally acceptable quality of life, and prognosis or time frame for possible recovery. Thus, a determination of nonbeneficial or medically futile treatment should take into account the predicted outcome, available medical evidence or experience, and patient expectations and wishes. There is considerable ethical debate about whose views should prevail in decisions regarding discontinuation or limitation of medical interventions when providers and families disagree about the benefit. Depending on the circumstances, a determination of nonbeneficial or medically futile treatment may be made by a team of clinicians, an ethics team, or a legal process. Local conditions and policies will prescribe the course to follow to implement a judgment that a medical intervention is not beneficial.



Differences regarding nonbeneficial and

medically futile treatments are best resolved through a fair, transparent process.

E. Palliative Care

A relatively recent phenomenon in many hospitals and care delivery systems is the development of palliative care services, interdisciplinary teams focused on maintaining a patient's comfort and quality of life. These teams are composed of medical, nursing, spiritual, psychological, and complementary therapies integrated around comfort as the goal of a patient's treatment. Prolonging life is sometimes a secondary outcome of palliative care, but it is not its primary intent. How well a patient lives, no matter how long the patient has to live, is the basic concern for palliative care, which provides treatments that will enhance a patient's quality of life. Palliative care teams should be enlisted when an interdisciplinary approach would help with a patient's pain, suffering, and distress. Palliative care can be an important adjuvant to the care of critically ill patients even before decisions to limit life-sustaining treatments have been made. Palliative care professionals can assist in end-of-life discussions with patients and families as the goals of care shift from cure to comfort.

It is important to distinguish palliative care from hospice. Hospice is a modality of care that focuses on the dying patient and aims to provide the optimal conditions for the end of life, forgoing a range of medical interventions that are primarily curative or life prolonging in nature. Palliative care may transition to hospice care, but is appropriate whenever a patient experiences pain or distress that is medical as well as existential. A terminal diagnosis may prompt a palliative care consultation.

F. Triage

The ICU is characterized by resource-intensive medical care. Because ICU technology, physician presence, and staffing are costly and limited, triage decisions regarding the allocation of these resources are frequently necessary. Triage is most often necessary when demand for critical care beds exceeds supply. Thus, patients may be denied admission based on resource constraints; be transferred from the ICU to another level of care based on severity of illness, prognosis, or wishes; or be transferred to another institution. The minimum severity of illness required to meet ICU admission criteria is likely to fluctuate within an institution (such as during influenza season or disaster

situations). Increasingly, however, patients who do not meet some minimum objective criteria for ICU admission are cared for on the wards regardless of the preference of patients, attending physicians, or staff. Critically ill patients who are not admitted to ICUs may have significantly greater morbidity and mortality rates. Therefore, triage choices represent life-and-death decisions that must be based upon criteria that are as objective as possible and applied uniformly. The ethical principle of beneficence is applied at the group or social level in such cases (maximize the benefit to the most) and is restrained by the principle of justice (treat all similar cases the same and different cases differently).

G. Organ Donation

After discussions regarding the extent of medical treatments have been completed and a decision to withdraw life support has been made, organ-procurement representatives should be allowed to evaluate the patient and conduct discussions with the patient's family or surrogate decision-maker about the potential for organ donation. Options include both conventional organ recovery after declaration of neurological death and potential organ donation after cardiac death. See **Appendix 6** for more information on brain death and organ donation.

IV. ETHICS AT THE BEDSIDE

When faced with an ethical dilemma, clinicians should incorporate one or more of the guiding ethical principles of healthcare into a framework for resolution. As each principle is systematically addressed, specific components of conflict can be identified and their analysis can often be simplified. The clinician should always start with the medical facts of the patient's case and then proceed to related topics. Specific issues may include:

- Who should be involved in the discussion
- Whether time constraints apply
- Whether the chronology of events or decisions is important
- What additional medical, legal, or social information is needed to facilitate decision- making
- What communication pathways will work best to resolve possible conflict
- What values or rules are important to the patient, the family, and the institution

- What areas of consensus already exist among the participants

Any unsettled matters often can be organized into a series of steps within the process of resolution. Depending on the nature of the dilemma, other experts may be called upon for specific input. An ethics consultant is often able to clarify the issues involved and to work toward a successful resolution of any differences. Some issues may need repeated examination to determine how to provide the highest level of medical and moral good for the patient. Some important elements of ethical decision-making are summarized in **Table 15-1**.

Table 15-1 Key Elements of Ethical Decision-Making

- Whenever possible, initiate discussions with patients regarding their preferences for life support before a medical crisis occurs and they lose capacity to make informed decisions.
- Utilize hospital and/or unit end-of-life care protocols. If protocols are not in place, healthcare providers should work with appropriate legal and ethical advisers to develop them.
- Direct discussions with patients and families to set appropriate goals of care based on patient values, wishes, and preferences, taking into account the best diagnostic and prognostic judgments.
- Ensure that all decisions related to consent, refusal to consent, limitation of resuscitation attempts, or termination of life support are clearly determined and documented according to policy and regulation.
- Make certain that all end-of-life care decisions are made with full disclosure of alternatives, implications, and potential conflicts of interest; are free of duress and coercion; and are made by persons who are competent and have decision-making capacity.
- Ensure adherence to ethical principles and professional and legal standards of medical conduct.
- Communicate clearly and document extensively.
- Develop consensus and a plan with the care team and, when indicated, involve support services such clergy, ethics committee or consultant, social services, palliative care services, or hospital council.

Each patient's situation is unique and requires continual, caring communication and reassessment of needs and goals. Clinical judgment, practical wisdom, common sense, compassion, and empathy are the key attributes required by clinicians involved in any ethically complex problem.

V. CASE STUDIES

A. Case 1: Advance Directives and Treatment Limitations

Mrs. Clark, a hospitalized 72-year-old woman who had abdominal wall hernia repair

10 days ago, sustained a cardiac arrest after massive aspiration. Cardiopulmonary resuscitation was initiated. She was found in asystole, but responded to intubation, defibrillation, and epinephrine after some difficulty. She was transferred to the ICU but developed severe acute respiratory distress syndrome. She now is unresponsive to painful stimuli, pupils are dilated and fixed, and corneal reflexes are absent. She is hemodynamically stable with improving respiratory function. She remains in a deep coma.

Analysis

This is a frequent scenario and often involves issues of limitation or withdrawal of treatments. The principles of autonomy, beneficence, nonmaleficence, and justice are presumed to apply in all clinical situations, though the role of each in a specific case may vary in importance. Whenever possible, the members of the healthcare team should reach a consensus regarding their prognosis and recommendations before family discussions are initiated. However, early in the course of ICU care, it must be determined whether the patient's preferences were specified in advance and/or who is authorized to make decisions on the patient's behalf. The patient's preferences and attitudes regarding an acceptable minimum quality of life are essential here. The ICU team should work closely with the patient's primary care physician, with whom the family is likely to have rapport. A palliative care consultation may be helpful. The palliative care team may facilitate discussions with the family, especially if the goals of care may transition to a focus on quality of life and comfort. The early involvement of clergy and members of the ethics team may be beneficial in establishing the values and goals of care that the patient would find acceptable.

The care team must convey a realistic attitude, using evidence-based data, accepted prognosis models, case studies, and anecdotal experience whenever possible, while acknowledging that all prognostication has a subjective component. Communication of medical information is important, especially regarding reflexes and responses that may appear to be signs for eventual recovery. Further diagnostic information should be considered if it may guide the surrogate decision-maker. A computed tomographic scan may strengthen the prognostic stance. The help of a neurologist may be indicated to underscore estimates of recovery from anoxic brain injury.

The patient's values, wishes, and directives, together with the diagnostic and prognostic information, should lead to establishing the appropriate goals of continued medical care. In light of these goals, the issues of tracheostomy, medical provision of fluids and nutrition, and further resuscitation attempts in the event of another cardiac arrest must be explored. It is appropriate to discuss both possible ramifications of discontinuing life support and long-term care issues. Documentation is important, and the elements of each

conversation and the bases for prognosis should be clear.

Finally, if the patient has left no advance directives and the surrogate cannot decide on the goals of care or the appropriateness of specific medical treatments, providers cannot coerce a decision based on their personal values, the guilt of the surrogate, or resource constraints. Continued support and guidance are always warranted; a decision may be forthcoming at a later date. However, when the patient is no longer critically ill and unstable, transfer to another unit is acceptable.

B. Case 2: Triage

Mrs. Williams, a 93-year-old patient with a history of dementia and medical problems including hypertension, diabetes, and end-stage renal failure, presents with sudden-onset seizures and waxing and waning mental status. She was recently discharged with a recommendation for hospice, which her family declined. She has a lactic acid measurement of 12 mmol/L, and the hospitalist is uncomfortable managing her on the medical floor and requests that she be transferred to the ICU. The ICU is full, and the best candidate for transfer is Mr. Aaron, a 45-year-old man with intracranial hemorrhage who was admitted 12 hours ago, is hemodynamically stable, and is not being ventilated. He is in danger of developing intracranial hypertension and worsening cerebral edema and may require intubation for airway protection.

Analysis

This is a triage/resource-allocation dilemma. The demand for ICU beds at the institution exceeds the supply, which requires a caring application of distributive justice. If defined hospital and ICU policies and protocols exist, they must be followed. The attending intensivist, as the leader of the critical care team, is responsible for determining how resources will be allocated. Mr. Aaron, the patient with the intracranial hemorrhage, is at high risk for acute decompensation outside the monitored setting of the ICU, and his long-term prognosis may not be better than that of Mrs. Williams; however, his clinical course is indeterminate at this time. Mrs. Williams has had a progressive decline in function, and medical therapy is becoming less beneficial. Aggressive care has not changed her course in the past, yet her family continues to hope for recovery and has chosen not to limit medical treatments or resuscitation attempts. It is appropriate to revisit the topic of limiting resuscitation attempts, calmly and dispassionately; however, to avoid coercing the surrogate into a decision based on feelings of guilt, the triage considerations should not be a focus of the discussion. The triage decision is made on the basis of criteria that take into account the good of all patients, not just that of Mrs. Williams. This is a medical staff decision, not an

individual patient care decision. There are three feasible alternatives: transfer Mrs. Williams to the ICU in place of Mr. Aaron, transfer Mrs. Williams to an institution with available ICU beds, or deny Mrs. Williams ICU admission at the present time.

Based on the immediate clinical situation, denial of ICU admission may be the most reasonable option. Though patient autonomy must be respected, it is not the preeminent ethical principle in situations of triage. Promoting the well-being of the patient with intracranial hemorrhage (beneficence) must be weighed against possible harm to the older patient with seizures and dementia (nonmaleficence). If justice requires maximizing the good to be produced by the allocation of scarce resources, and this is achieved by refusing to admit Mrs. Williams to the ICU, it is the ethically correct decision. Supportive measures for Mrs. Williams should continue to the extent possible on the ward. The family should be notified that she has taken a turn for the worse and that best available care is being provided. If she continues to deteriorate without a response to therapy and an ICU bed remains unavailable, discussions with Mrs. Williams' family regarding the value of aggressive therapy may be appropriate. Careful documentation must accompany all treatment decisions and discussions. Clergy and the ethics committee may be notified if appropriate. Administrative notifications or advice of hospital counsel may also be needed.

C. Case 3: Nonbeneficial or Medically Futile Treatments and End-of-Life Care

Ms. Crocker is a 40-year-old divorced woman with paralysis from a rare metastatic spinal cord tumor. She was discharged to hospice from another facility and then consulted a radiation oncologist with hopes of achieving palliation and more time with her three young children. The radiation oncologist reluctantly offered to try a single massive dose of radiation. She was admitted, but before the radiation therapy, she developed severe respiratory distress. She now is intubated and ventilated, is hemodynamically unstable, and has progressive neurological deterioration. Her parents and family indicate that she would like "everything done" to possibly prolong her life and to complete the planned radiation therapy.

Analysis

This is an unfortunate scenario repeated often in similarly tragic circumstances. Next of kin often say their loved one would want everything done, even under circumstances that indicate likely futility. The term *medical futility* is a value-laden concept and may not have the same meaning for providers and patients or their families. The term *nonbeneficial medical treatment* better reflects a medical judgment as to the possible effects of a treatment. In this case, progressive neurologic deterioration prohibits any

further consideration of radiation for Ms. Crocker. The family still has hope of recovery in spite of her grim prognosis. While patient autonomy should be respected, there are many barriers and limits to exercising autonomy in the ICU. The patient's loss of decision-making capacity often leads to disagreements among surrogates and family members. There may be uncertainty in interpreting the patient's advance directives. Determining which values would now be most important to the patient is frequently a source of discord. In this case, Ms. Crocker's family must be made aware that in addition to respecting her wishes, they must consider what would be in the best interests of their loved one. A reasoned clinical assessment would be that prolonging her life under these circumstances will result in harm to Ms. Crocker without compensating benefit. Continuing aggressive medical treatments would not be beneficial. Recommending compassionate extubation and comfort as the goals of care is ethically appropriate. Sensitive presentation of this alternative to Ms. Crocker's family, along with the grounds for the clinical judgment, may eventually lead the family to agree that focusing on her comfort is in her best interest. Ethics consultation, clergy counselling, and palliative care services may assist in this discussion and facilitate this transition in the goals of her care.

Key Points

Ethics in Critical Care Medicine

- Healthcare professionals have an obligation to act in a patient's best interests based upon the ethical principles of autonomy, beneficence, nonmaleficence, and justice.
- When faced with an ethical dilemma, consensus from the healthcare team on the diagnosis, prognosis, and recommended treatment plan facilitates consistent communication and documentation and minimizes liability risks.
- Specific components of conflict within an ethical dilemma can be identified and the analysis simplified when each ethical principle is addressed systematically.
- Life support may be withdrawn at the end of life, but care is never withdrawn.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

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19. Wueste DE. A philosophical yet user-friendly framework for ethical decision making in critical care nursing. *Dimens Crit Care Nurs*. 2005;24:70-79.

Suggested Website

1. Society of Critical Care Medicine/Guidelines. www.SCCM.org

CRITICAL CARE IN INFANTS AND CHILDREN: THE BASICS

Objectives

- Review pediatric physiology and pathology.
- Understand differences in adult and pediatric critical care.
- Describe modifications to adult therapies in order to support children appropriately.

Case Study

A 6-month-old female infant, who was born at 30 weeks' gestation, presented with fever, tachypnea, rhinitis, and coughing for 4 days. On arrival at the pediatric emergency department, she had a heart rate of 150 beats/min, respiratory rate 60 breaths/min, oxygen saturation of 90%, and temperature of 38.5°C (101.3°F). She had subcostal and upper sternal retractions, was tachypneic and agitated, and had copious upper airways secretions. Auscultation revealed diffuse rhonchi. She was given 100% oxygen and albuterol via a nebulizer, with minimal improvement.

– What is the most important initial intervention?

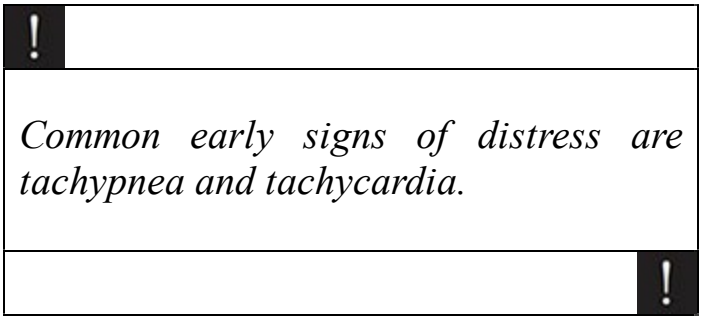
– What are the most immediate treatment strategies?

I. INTRODUCTION

The preceding chapters have emphasized principles of critical care and management of a variety of conditions in adult patients. This chapter focuses on the basic management of certain pediatric conditions. An in-depth review of this subject can be found in the

Pediatric Fundamental Critical Care Support (PFCCS) program. This chapter will introduce a key PFCCS learning and management concept that can be summarized with the acronym, **DIRECT: D**etection, **I**ntervention, **R**eassessment, **E**ffective **C**ommunication, and **T**eamwork. Each section is preceded by a case study that will illustrate this concept.

Infants and children have different body habitus and immature physiology and anatomy. Therefore, manifestations of critical illness differ from those in adults, and interventions must be modified.



II. GENERAL EXAMINATION

Because young children are unable to verbalize specific complaints, medical evaluation depends heavily upon physical examination and information obtained from a parent or guardian. Although early signs of distress may be subtle, early recognition may increase the likelihood that interventions will be successful and prevent more serious progression. When early signs of illness are missed, healthcare providers may assume that a child's condition has suddenly deteriorated; in fact, the seemingly abrupt change reflects an advanced point along a continuum of physiologic compromise. **Table 16-1** lists important factors to be considered in the general examination of pediatric patients. **Tables 16-2** and **16-3** provide age-appropriate normal values for vital signs and blood volume.

Table 16-1	Important Aspects of the Physical Examination

Skin perfusion: Check for loss of normal pink mucosa and nail beds, mottling that has replaced the usually uniform skin color over the trunk and extremities, skin that has lost its warmth, and the slowing of capillary refill. Capillary refill should be less than 2 seconds and determined with the extremity above the level of the patient's heart.

Degree of hydration: A dehydrated infant may have a sunken fontanelle in addition to signs that may be seen in older children, such as absent tears, sunken eyes, skin tenting, and dry mucous membranes. A severely dehydrated child may look toxic and lethargic.

Level of spontaneous reactivity and responsiveness: Ill children may have increased irritability initially, often followed by decreased responsiveness and increasing flaccidity. In most infants, alertness can be evaluated by observing their ability to fixate on objects, particularly a parent's face. Infants should turn toward sound and should follow an object horizontally and, within 1 month of age, vertically. Older children should exhibit stranger anxiety and show clear recognition of parents.

Position spontaneously assumed for comfort: Illness may be marked by the inability to find a position of comfort or to find more than a single position of comfort. Patients should not be forced to assume another position, as this could potentially compromise a tenuous airway.

Tachypnea: Rapid breathing is an important sign of illness in infants and young children. Etiologies include respiratory disease, hypovolemia, hyperviscosity syndromes, hyperglycemia, heart failure, adverse drug effect, metabolic acidosis, fever, pain, and anxiety.

Bradypnea: This ominous sign may be due to hypothermia, central nervous system injury, drug-induced depression, neuromuscular disease, severe shock, metabolic disorders, and respiratory exhaustion.

Grunting during exhalation: This ominous sign may occur as part of respiratory distress, pain, or intra-abdominal disorders.

Nasal pathway: The nose is the primary route for normal breathing in an infant. Total airway resistance and the potential for compromised breathing are increased significantly in infants with nasal congestion or increased secretions, or by the presence of a nasogastric tube. Nasal flaring is a sensitive indicator of respiratory distress in the infant.

Early hypovolemic shock: The most reliable indicators of early compensated hypovolemic shock in children are persistent tachycardia, cutaneous vasoconstriction, and decrease in pulse pressure. Signs of decreased tissue perfusion include skin mottling, prolonged capillary refill, and cool extremities. Systemic arterial blood pressure is frequently normal because of a compensatory increase in systemic vascular resistance. The neurologic status is normal or only minimally impaired. It remains important to measure blood pressure, as a low value suggests a decompensated state and requires immediate intervention.

Seizures: Seizures may be characterized by decreased alertness (the infant does not regard parents or track an object across the visual field), staring, autonomic changes (tachycardia, elevated blood pressure, and dilated pupils), apnea, and subcortical muscle activity (bicycling movements of the legs, swimming movements of the arms, sucking, or tongue-thrusting movements). Tonic-clonic muscle motion may not occur in infants due to an immature nervous system.

Infection: Fever should always suggest the possibility of infectious disease. In the neonate, infection usually involves bacteremia. Respiratory distress, temperature instability (including hypothermia), and gastrointestinal signs are common clinical findings of sepsis.

Table 16-2 Vital Signs in Children[a]

Age Group	Heart Beat (beats/min)	Respiratory Rate (breaths/min)	Blood Pressure (mm Hg)
Premature	120-170	40-70	55-75/35-45
Newborn[b]	110-160	30-60	65-85/45-55
Infant	90-150	25-45	70-100/50-65
1-3 years	80-125	20-30	90-105/55-70
3-6 years	70-115	20-25	95-110/60-75
6-12 years	60-100	14-22	100-120/60-75

>12 years	60-100	12-18	100-120/70-80

[a]In children, MAP can be estimated by 55 + (age x 1.5).
[b]In neonates, MAP can be estimated by gestational age.

Table 16-3	Blood Volume in Children	
Age Group	**Weight[a] (kg)**	**Blood Volume (mL/kg)**
Premature	0.5-1.5	100
Neonate	3.5	90
6 months	6.5	80
1 year	10	75
Adolescent	>40	65-70

[a]Weight can be estimated by 2 x (age + 4)

III. EVALUATION BY ORGAN SYSTEM

Healthcare providers attending to critically ill pediatric patients must be able to promptly recognize respiratory, cardiovascular, metabolic, immunologic, and neurologic problems in children. Important differences between children and adults and basic treatment strategies are summarized below.

A. Respiratory System/airway

Pediatric airway management is challenging due to the anatomic differences that exist between small children and adults as well as among children of different ages. Recognition and interruption of the progression from respiratory compromise to respiratory failure is fundamental to pediatric airway management. The ability to recognize airway compromise and to establish and maintain a patent airway is essential.

1. Anatomic and Physiologic Considerations

In the airway of a child, changes will evolve gradually from birth until approximately 8 years of age, when the airway becomes anatomically similar to that of an adult. In addition to airway disorders related to small size and normal anatomic development, congenital abnormalities can affect the pediatric airway. After children reach age 8, their upper airway problems become similar to those found in adults.

Children have important thoracic and pulmonary differences from adults. The thorax is more cartilaginous in infants and young children and therefore more compliant. Increased intrathoracic pressure during respiratory distress is less efficient at augmenting tidal volume because the chest retracts inward, reducing tidal ventilation and indirectly increasing the work of breathing. Soft-tissue retractions similarly reduce thoracic volume during vigorous respiratory efforts. The infant's ribs are aligned in a more horizontal plane and decrease the inspiratory displacement of the thorax in the anteroposterior plane, further decreasing the efficiency of the bellows effect. The points of muscular insertion of the diaphragm on the thorax also are more horizontal in the infant, similar to the thorax of an adult with obstructive lung disease and a flattened diaphragm. Therefore, the lower thorax may be drawn inward during inspiration, causing reduced inspiratory volume. Immature intercostal muscles cannot assist active ventilation for several years after birth; thus, more dependency is placed upon diaphragmatic function and excursion. Compromise of diaphragmatic excursion by gastric distention, abdominal distension, and surgery may quickly compromise respiratory function.

Alveolar size and number, as well as lung compliance, increase substantially during childhood. Tidal volume remains fairly constant through childhood at 6 or 7 mL/kg. Smaller anatomic conducting airways may produce high resistance if further narrowed by inflammation, edema, mucus, bronchospasm, and bronchiolitis. High peripheral airway resistance may also alter exhalation, induce dynamic closure of the airways, and cause auto-positive end-expiratory pressure (auto-PEEP).

2. Airway Management

The first consideration in airway management is head position. An obtunded child or one otherwise unable to maintain a position of comfort should be placed in the sniffing position to minimize upper airway obstruction from soft tissues. The sniffing position is accomplished by placing the child on a hard surface and rotating the head back so that the child's face is directed upward. The head is extended while the neck is flexed. A roll beneath the shoulders can help maintain the infant's head position due to the relatively high head circumference. In the child older than 2 years, the sniffing position may be accomplished by placing a folded towel or sheet under the child's occiput. If able, children should be allowed to choose a position of comfort. Gentle in-line stabilization in the neutral position is used in children with suspected cervical spine injury, and further manipulation is restricted to the jaw-thrust maneuver. Insertion of an oropharyngeal or endotracheal airway must be done with minimal cervical movement. Assistance from video laryngoscopes may be helpful in this setting.

Simply suctioning the nasal passages can be an important intervention in establishing airway patency.

An infant's oxygen consumption is two to three times that of an adult. Residual oxygen reserves in the lung are rapidly depleted if oxygen availability is compromised, leading quickly to hypoxemia. Children have lower hemoglobin levels than adults. Because cyanosis occurs only when a critical level of unsaturated hemoglobin is present, blood oxygen content will be lower than adults before cyanosis is evident. Therefore, 100% oxygen should be administered to all dyspneic children in whom respiratory compromise is suspected. Pulse oximetry is accurate and should be used to titrate the fraction of inspired oxygen. The mask used for oxygen supplementation may cause agitation in children, and several devices should be available for trial. Supplemental oxygen should be warmed and humidified if possible to avoid heat and evaporative water losses from the airway or secretion thickening. The nasopharynx in infants is large compared to the tidal volume and inspiratory flow achieved, so a nasal cannula will provide a higher inspired oxygen concentration than in an adult. Issues relating to intubation are summarized in **Table 16-4**.

100% oxygen should be promptly administered to children in distress.

Table 16-4 Endotracheal Intubation in Children

- Positive pressure created during bag-mask ventilation may quickly cause gastric distension; a nasogastric tube may be needed. Gastric distension not only promotes vomiting and aspiration but also interferes with ventilation and leads to acceleration of hypoxemia during mask ventilation.
- Because the infant has a large occiput, the head flexes forward onto the chest when the infant is supine and the head is midline. In the absence of neck injury, the child's head should be placed in the sniffing position with the assistance of a shoulder roll. However, extreme neck extension can obstruct the airway.
- The tongue in infants and children up to approximately 2 years of age occupies a relatively large

portion of the oral cavity and may cause obstruction to spontaneous or assisted ventilation and intubation.

- The anterior and cephalad position of the larynx makes blind nasal intubation difficult. In addition, the adenoidal tissue may be enlarged. Blind passage of a relatively rigid tube through this area can cause uncontrollable bleeding. The nasal route is discouraged.
- The epiglottis is floppy and often obscures the glottic opening because of its angle of attachment to the larynx and its relative lack of cartilage.
- Cricoid pressure may improve exposure of the glottis. The maneuver is accomplished by applying gentle pressure toward the spine at the level of the cricoid cartilage without displacing the larynx in the cephalad direction. Lateral displacement may also be helpful for tracheal visualization.
- An oversized endotracheal tube may cause inflammation, edema, and permanent injury to the trachea. In general, a properly sized tube is about the diameter of the child's small finger. In children older than 2 years, the following formula is used to determine the appropriate uncuffed endotracheal tube size: age/4 + 4, with 0.5 subtracted for cuffed tubes. The use of cuffed endotracheal tubes is safe for infants and children. Cuffed endotracheal tubes may be especially useful in certain clinical conditions, such as poor lung compliance, large air leak, or high airway resistance. The cuff inflation pressure should be monitored and ideally <20 cm H_2O and not >30 cm H_2O.
- The trachea is short enough that special care must be taken to avoid bronchial placement of the endotracheal tube. A formula to estimate depth is the endotracheal tube inner diameter x 3.

3. Respiratory Failure

The anatomical and developmental factors described result in low respiratory reserve in the pediatric patient. Therefore, the etiology of cardiopulmonary arrest in pediatric patients is most commonly the result of a respiratory disorder. The majority of deaths in children (especially those younger than 1 year) involve respiratory disorders resulting from infection, poisonings, trauma, submersion or suffocation, and sudden infant death syndrome. Airway obstruction, aspiration, and apnea are also among the most common hazards to respiratory function. Thus, assuring a patent airway is the most important first step in care of the child with respiratory compromise. Neonates and young infants use the nasal airways as their primary route of respiration and so nasal airway obstruction may lead to dyspnea. In young children, common causes of respiratory failure include airway obstruction, congenital disorders, infections (viral croup, bacterial tracheitis, or less commonly, epiglottitis), or ingestion or aspiration of a foreign body (**Table 16-5**). Clinical examination helps to identify the site of obstruction and treatment options.

Table 16-5	Causes of Respiratory Failure
Premature neonates	Apnea of prematurity
	Infant respiratory distress syndrome (surfactant deficiency and ineffective chest bellows)
Term neonates	Bacterial pneumonia Meconium aspiration Congenital airway abnormalities

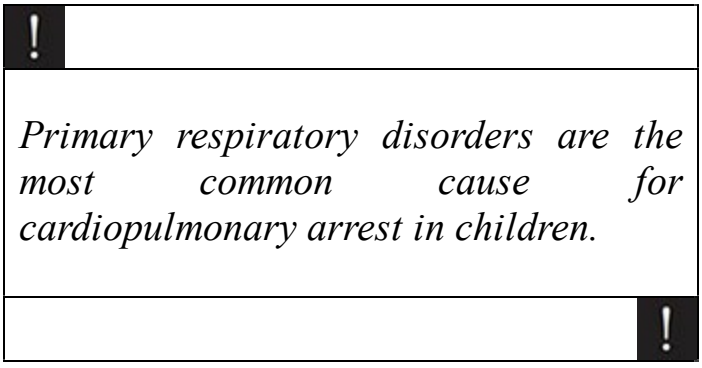
Infants, toddlers	Pneumonia Bronchiolitis Asthma Foreign-body aspiration Upper airway obstruction due to infection

Airway obstruction above the thoracic inlet tends to cause stridor (inspiratory noise), whereas intrathoracic obstruction tends to cause wheezing (expiratory noise).

Upper airway infection (viral croup) and other conditions (e.g., laryngeal edema) may be relieved by racemic epinephrine nebulization (0.05 mg/kg, maximum of 0.5 mg in 3 mL normal saline) and intravenous steroids (dexamethasone 0.3 mg/kg every 6 hours).

Lower airway infections of viral origin (respiratory syncytial virus) are frequent in small children and can produce significant wheezing that may respond to bronchodilators.

Children with asthma or acute bronchospasm should receive supplemental oxygen, inhaled β-agonist, and corticosteroids (methylprednisolone). β-Agonists may be administered intermittently or as continuous nebulization therapy. The dose will depend on the patient's age. Children younger than 1 year may receive 0.63 mg/3 mL normal saline; those between 1 and 5 years get 1.25 to 2.5 mg/3 mL normal saline. For children between 5 and 12 years, the dose is 2.5 mg, and those older than 12 years receive 2.5 to 5 mg every 4 to 6 hours. The suggested initial dosage for methylprednisolone is 1 mg/kg intravenously every 6 hours. Anticholinergic therapy with ipratropium bromide (500 μg/2.5 mL normal saline) may be beneficial. In acute bronchospasm, intravenous terbutaline: loading dose of 2 to 10 μg/kg infused for 10 minutes, followed by a continuous infusion of 0.1 to 10 μg/kg/min may also be given.



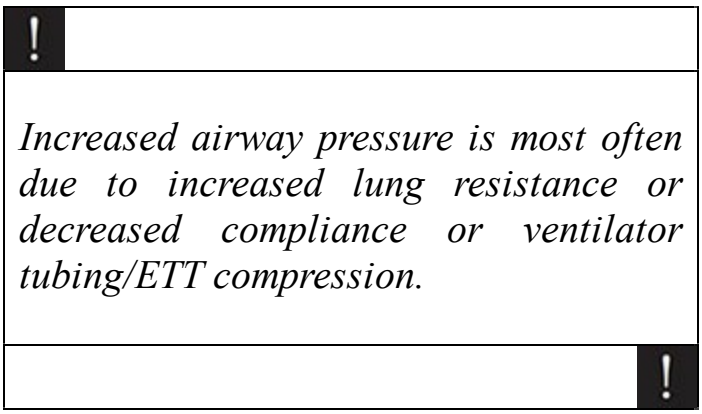
Patients with upper or lower conditions, including bronchiolitis or asthma requiring low oxygen concentrations, may benefit from an oxygen-helium mixture (30% oxygen, 70% helium).

4. Mechanical Ventilation

The principal concepts of mechanical ventilation are similar in pediatric patients, but specific settings and adjustments may vary. The suggested initial mechanical ventilation settings for infants who weigh <5 kg are presented in **Table 16-6**.

Table 16-6	Initial Mechanical Ventilator Settings: Infants Weighing <5 kg
Mode	Time-cycle, pressure- or volume-limited ventilation
Peak inspiratory pressure	Start at 18-20 cm H_2O and titrate to a pressure that provides adequate chest movement and tidal volumes
Tidal volume	6-8 mL/kg (avoid >10 mL/kg)
Respiratory rate	30-40 breaths/min, adjust to maintain acceptable $Paco_2$ levels
Positive end-expiratory pressure	5 cm H_2O

Remember that tidal volumes measured by the ventilator also incorporate breathing circuit expansion and gas compression volumes, which can constitute a substantial portion of the total volume. Loss of ventilation can occur because the ventilator tubing is distended lengthwise and circumferentially by increases in peak airway pressure that create a backpressure. The amount of gas from the tidal inhalation that is trapped in the ventilator tubing is a function of the airway pressure and the distensibility (compliance) of the tubing. Soft plastic used in ventilator tubing distends more than hard plastic, increasing the compliance volume. As much as 3 to 4 mL of gas per centimeter H_2O airway pressure may be trapped in the adult ventilator tubing at end inspiration. This gas remains in the tubing at peak inhalation without entering the lung and then exits the circuit through the exhalation valve as exhalation begins. This loss of alveolar ventilation is of less consequence in an adult with a tidal volume of 500 mL than it is in a child with a tidal volume of 150 mL. Specialized pediatric and neonatal circle systems are recommended, as they are less compliant.



Suggested initial ventilator settings for pediatric patients >5 kg are summarized in **Table 16-7**. If volume-controlled ventilation is used, attention to the peak inflation pressure prevents barotrauma (keep <30 cm H_2O). If pressure-controlled ventilation is used, attention to tidal volume (<8 mL/kg) is necessary to prevent hypoventilation or volutrauma, and tidal volume may fluctuate with changing lung compliance. Always observe the chest rise at initiation of mechanical ventilation and when tidal volume is adjusted. Sedation may be useful with increased respiratory rates and/or increased tidal volume.

Table 16-7	Initial Mechanical Ventilator Settings: Infants Weighing >5 kg
Mode	Time-cycled, (volume- or pressure-limited)
Tidal volume	6-8 mL/kg for normal lungs or 6 mL/kg for acute lung injury/acute respiratory distress syndrome (do not exceed 10 mL/kg)
Peak inspiratory pressure (pressure-limited SIMV)	Start at 18-20 cm H_2O and titrate to a pressure that provides adequate chest movement and tidal volume not to exceed 10 mL/kg
Inspiratory time	Babies: 0.5-0.6 sec Toddlers: 0.6-0.8 sec School-aged children/teens: 0.8-1.2 sec
Respiratory rate	Rates vary according to age: – Toddlers, 25-35/min – Preschool, 20-30/min – School age, 15-25/min – Teens, 10-20/min Adjust to maintain acceptable Pa_{CO_2} levels
Pressure support	5-10 cm H_2O above PEEP to overcome resistance of endotracheal tube
Positive end-expiratory pressure	5 cm H_2O; higher levels in acute lung injury for alveolar recruitment

Abbreviation: SIMV, synchronized intermittent mandatory ventilation; PEEP, positive end-expiratory pressure

B. Cardiovascular System

1. Anatomic and Physiologic Considerations

The circulating blood volume is higher per kilogram in children than in adults, but the absolute volume remains low because of the small body size. Therefore, small amounts of blood loss are less tolerated by children. Blood replacement is indicated when 5% to 10% of the circulating volume has been lost. Allowable blood loss can be calculated using the formula:

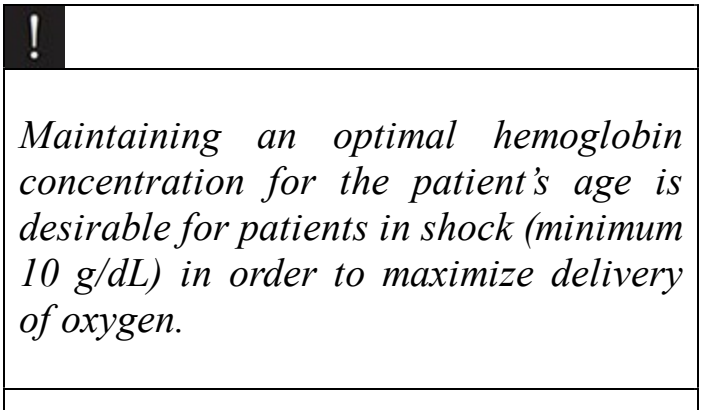
Allowable Blood Loss = [EBV*(Hi-Hf)]/Hi

where Hi is initial hemoglobin, Hf is allowed hemoglobin, and EBV is estimated blood volume in mL/kg.

Cardiac output is high per kilogram of weight at birth, but the absolute amount is small (~ 600 mL/min) and largely depends on a rapid heart rate because the small uncompliant heart results in low stroke volume. In children, cardiac output remains dependent upon changes in heart rate. Therefore, bradycardia may greatly limit systemic perfusion and is most often an ominous sign of significant hypoxemia or acidosis. In children younger than 6 years, a heart rate <60 beats/min with decreased perfusion (low blood pressure, poor pulses) is an indication for chest compressions. Other arrhythmias usually do not produce significant changes in cardiac output, except when tachyarrhythmias occur, including sustained supraventricular tachycardia. Ventricular arrhythmias are uncommon but, when present, may signify congenital heart disease, myocarditis, cardiomyopathy, electrolyte abnormalities, or asphyxia.

Myocardial maturation influences the heart's response to volume challenges intended to increase preload. Before the age of 8 weeks, infants may not respond to a fluid bolus by increasing cardiac output, but thereafter the response is similar to that of adults. Central venous pressure does not necessarily reflect circulatory blood volume or left ventricular efficiency.

Pulmonary vascular resistance falls quickly after birth, reaching normal adult levels by 8 weeks of age. However, the pulmonary vasculature may remain highly reactive to hypoxia, hypercapnia, hypothermia, or acidosis, thereby increasing afterload to the right ventricle. Myocardial anatomy changes in such a way that after birth, the larger right ventricle decreases its mass and the left ventricle increases in size and mass. Similarly, the neonatal response to catecholamines is limited until sympathetic nervous system innervations and β_1-receptors increase over several weeks. Therefore, the physiologic effects of exogenous catecholamine administration may be variable, and careful titration to the individual child's response is essential.



2. Shock

Case Study

A 2-week-old full-term neonate presents with 3 days of nonbilious projectile vomiting and agitation, worsened by feeding attempts. The mother reports that he has had regurgitation of feedings since birth, with worsening in the last 3 days. His last wet diaper was 1 day ago. Upon examination, the infant is awake and moving his extremities, but appears weak. Fontanelles are sunken, mucous membranes are dry, and the infant appears jaundiced. His heart rate is 190 beats/min, respiratory rate 50 breaths/min, blood pressure 44/25 mm Hg, and temperature 37°C (98.6°F).

– What is the differential diagnosis and the most likely etiology?

– What initial intervention is indicated?

– What diagnostic modalities are indicated?

Children are particularly susceptible to shock states. Shock in pediatric patients is defined and categorized as in adults (**Chapter 7**), but the etiologies may differ. Timely recognition of the shock state and aggressive intervention are essential to obtaining an optimal outcome (**Table 16-8**). As soon as the diagnosis of shock is considered, early cardiopulmonary monitoring, vascular access, and treatment must be implemented. Fluid resuscitation is the initial therapy for most forms of shock. Rapid restitution of circulating intravascular volume is critical to restore tissue oxygenation and perfusion and avoid end-organ damage. Initial volume expansion with isotonic crystalloid solutions (normal saline or Ringer lactate solution) at 20 mL/kg is recommended, repeated up to a total of 60 mL/kg in the first 15 minutes. If possible, minimize the total amount of normal saline, preferring Ringer lactate solution or PlasmaLyte, as normal saline can independently cause acidosis by changing strong ion balance. Smaller volumes of 5 to 10 mL/kg should be used in patients with suspected myocardial dysfunction. Although hepatomegaly can be a sign of fluid overload in the pediatric patient, it must be viewed with caution. Disease processes common to children (e.g., asthma, respiratory syncytial virus, pneumonitis) can cause lung hyperinflation and downward displacement of the liver. Other signs of volume overload also should be considered in the evaluation of these patients. If a child with an enlarged liver fails to respond to the initial fluid administration, radiologic examination of the chest may help to evaluate heart size. In children, crackles may occur late in the process of developing

heart failure, and a gallop may be difficult to discern in infants with tachycardia.

Table 16-8	Management of Pediatric Shock
Detection	Evaluate and perform assessment of general appearance, airway, breathing, circulation, pertinent history, and physical exam Attach appropriate monitors Recognize the type of shock and categorize the severity
Intervention	Provide 100% oxygen (except if suspecting cyanotic heart disease in a neonate) Obtain appropriate intravenous/intraosseous access (preferred) Administer appropriate intravenous fluids – 20 mL/kg bolus isotonic crystalloids – Repeat fluid bolus with reassessment Place urinary catheter
Reassessment	Re-evaluate airway, breathing, circulation, and mental status after each intervention Repeat fluid at 20 mL/kg Monitor ongoing losses Check the therapeutic end points in resuscitation – End-organ function – Heart rate, blood pressure, signs of perfusion – Mental status – Urinary output Obtain serum electrolyte measurements, monitor hypo/hypernatremia, acidosis, blood urea nitrogen/creatinine, glucose
Effective communication	Define team member roles and responsibilities Communicate effectively with other caregivers Promote collegial interaction and knowledge sharing

a. Hypovolemic Shock

The most common cause of shock in the pediatric patient is acute hypovolemia resulting from increased fluid and electrolyte losses (gastrointestinal disorders) or blood loss resulting from trauma. Hypovolemia also can be caused by capillary leak due to intestinal ischemia from volvulus, intussusception, or necrotizing enterocolitis. A detailed medical history should be obtained from the patient's caregiver and/or referring institution. A history of increased fluid losses (vomiting and diarrhea), lethargy, and decreased urine output is usually found in infants with hypovolemic shock. Blood pressure is maintained longer in hypovolemic children than in adults. Capillary refill and extremity temperature are much more reliable indicators of hypovolemia because they may become abnormal much earlier than blood pressure in the child with shock. Children with hypovolemic shock may require 40 to 60 mL/kg of isotonic fluids (Ringer lactate solution preferred, or normal saline). Hypotonic or dextrose-containing fluids are not indicated during the initial treatment phase. Transfusion of packed red

blood cells (15 mL/kg) should be considered in patients with hemorrhagic shock when signs of shock persist despite adequate isotonic fluid resuscitation. Inotrope/vasopressor support should be considered for patients who do not respond to isotonic fluids. Those with concurrent adrenocortical problems can be refractory to fluids and inotropes and will respond only to glucocorticoid replacement (hydrocortisone 1-2 mg/kg/day).

b. Distributive Shock

As in adults, the most common cause of distributive shock in pediatric patients is sepsis. Other etiologies are similar to those in adults with the addition of congenital adrenal hyperplasia. Septic shock is characterized by changes in mental status, fever or hypothermia, and perfusion abnormalities such as vasodilation (warm shock) or vasoconstriction (cold shock). The therapeutic goal in septic shock is to restore and maintain optimal organ perfusion and oxygenation. Acceptable goals include restoration of the patient's mental status and urine output (1 mL/kg/h). Children in septic shock are usually severely hypovolemic and will respond to aggressive fluid resuscitation. Initial rapid fluid resuscitation with isotonic fluids (20 mL/kg) is suggested. Typical fluid requirements range from 40 to 200 mL/kg during the initial phase of resuscitation. Fluid choices are crystalloids and colloids (5% albumin, dextran, gelatin). Vasopressor support with central norepinephrine (0.05-0.3 μg/kg/min) is recommended as the first choice in patients with fluid-refractory vasodilated shock. Vasopressin (0.001 U/kg/min) or epinephrine (0.05-0.3 μg/kg/min) may be considered in patients unresponsive to norepinephrine. Dopamine (5-10 μg/kg/min) is recommended as the first choice in patients with fluid-refractory cold shock. Epinephrine (0.05-0.3 μg/kg/min) may be considered in patients unresponsive to dopamine. Milrinone (0.5-1 μg/kg/min) or dobutamine (5-10 μg/kg/min) may be administered with caution to patients with low cardiac output and elevated systemic vascular resistance states (vasoconstricted) after fluid resuscitation. Use of corticosteroids is indicated in those with vasopressor resistant shock, purpura fulminans, or suspected adrenocortical problems (chronic steroid use in immunodeficiency, malignant disease, collagen vascular disorders). The initial recommended dose of hydrocortisone is 1-2 mg/kg/day. Early transfer to a pediatric ICU for inotropic support and invasive cardiopulmonary monitoring is indicated in patients not responding to fluid resuscitation. Infants with sepsis are often profoundly hypoglycemic on presentation and glucose determinations should be performed in suspected sepsis.

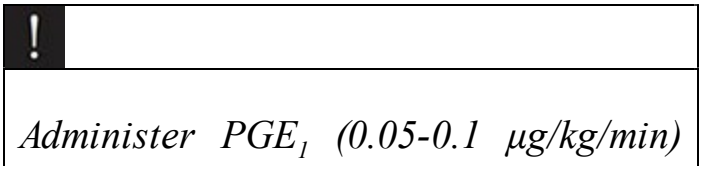
c. Cardiogenic Shock

Congestive heart failure is the most common presentation of congenital heart anomalies in children and often precedes cardiogenic shock. Congestive heart failure can often be

the result of acute or chronic changes in the heart's preload, afterload, contractility, or heart rate and rhythm. Signs and symptoms vary depending on the type of lesion. Newborn (0-28 days) infants with ductal-dependent lesions (eg, coarctation of the aorta, transposition of the great vessels, tricuspid atresia) will typically present in profound shock with a history of poor feeding, tachypnea, lethargy, cyanosis, thready or absent femoral pulses, and poor or absent urine output (obstructive shock). These patients will require prompt initiation of prostaglandin E1 (PGE_1) and inotropes in addition to isotonic fluids. Patients with non-ductal-dependent lesions can present beyond the newborn period with a history of tachycardia, gallop rhythm, heart murmur, tachypnea, hepatomegaly, and failure to thrive. These patients will often respond to diuresis with a loop diuretic (furosemide 0.5-1 mg/kg) rather than fluid resuscitation and to inotropic support (milrinone 0.5-1 µg/kg/min or dobutamine 5-10 µg/kg/min) and/or afterload reduction. Fluid resuscitation must be titrated cautiously. Early transfer to a pediatric ICU for further monitoring, inotropic support, and a complete evaluation by a pediatric cardiologist is recommended. Other common etiologies of cardiogenic shock include hypoxic-ischemic episodes after acute life-threatening events, near drowning, or strangulation.

d. Obstructive Shock

Congenital lesions that interfere with outflow from the left ventricle, such as coarctation of the aorta or interrupted aortic arch, commonly cause obstructive shock in infants. They develop signs of shock when the ductus arteriosus closes, thus interfering with blood delivery to the distal aorta. A history of poor feeding, lethargy, decreased or absent urine output, decreased or absent femoral pulses, and metabolic acidosis is frequent. When treating hypotension in a child with non-hypovolemic shock, initial titrated boluses of 10 to 20 mL/kg crystalloid, up to 40 mL/kg, may not be effective. Inotropic support with dobutamine (5-10 µg/kg/min) and a PGE_1 infusion should be initiated rapidly to reopen the ductus arteriosus and restore perfusion to the distal aorta in infants and children with suspected left heart lesions. The usual dose is PGE_1 0.05 to 0.1 µg/kg/min as a continuous infusion. The side effects of PGE_1 infusion include periodic breathing, apnea, and peripheral vasodilatation, so the clinician must be prepared to support the patient's airway, provide ventilation, and administer additional fluids. Once the ductus arteriosus has reopened, hyperventilation and hyperoxia must be avoided, because both of these conditions will lead to preferential pulmonary blood flow through the ductus and will worsen systemic shock and distal perfusion.



for newborns in shock until a ductal-dependent lesion can be ruled out.

C. Metabolism/temperature

Case Study

A 2-year-old male child is brought to the emergency department with a history of vomiting and diarrhea for 1 week. His heart rate is 150 beats/min, respiratory rate 20 breaths/min, blood pressure 70/50 mm Hg, and temperature 37.5°C (99.5°F). The child appears lethargic, has dry mucous membranes, and poor skin turgor. During your examination, he has a tonic-clonic seizure broken with rectal diazepam.

– What is the most likely etiology of the seizures?

– What is your initial management strategy?

– What diagnostic modalities are indicated?

Pediatric patients are particularly susceptible to water and electrolyte abnormalities and experience temperature regulation problems frequently. The more common issues that can result in critical illness are examined.

1. Water/Temperature

Insensible water loss is higher in children than in adults because children have a higher ratio of surface area to body mass. This higher evaporative fluid loss, combined with a higher metabolic rate, emphasizes that dehydration may occur quickly. Therefore, children require a greater amount of fluid per kilogram than adults do, but this volume is still a low absolute amount because of a child's small size. Titration of these small volumes usually requires infusion pumps for precise administration and frequent adjustment of fluids to assure adequate replacement of deficits lost from all sites. Several approaches to fluid (**Table 16-9** and **16-10**) and electrolyte replacement help the clinician estimate the actual requirements. Remember that infusion rates may be so low (<1 mL/h) that drips may require a carrier fluid, and this should be accounted for in fluid calculations.

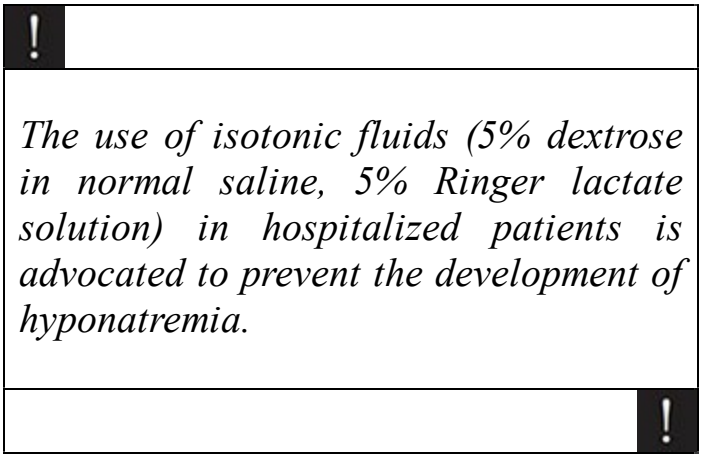
Table 16-9	
Detection	Evaluate and perform assessment of general appearance, airway, breathing, circulation, pertinent history, and physical exam Attach appropriate monitoring devices Recognize the respiratory physiology disorder and type of dehydration (hyponatremic), and categorize the severity
Intervention	Provide 100% oxygen Obtain appropriate intravenous/intraosseous access (preferred) – Administer appropriate intravenous fluids – 20 mL/kg bolus of isotonic crystalloids – Repeat fluid boluses with reassessment Place urinary catheter Obtain serum electrolyte measurements; monitor hypo/hypernatremia, calcium, and glucose
Reassessment	Reevaluate airway, breathing, circulation, and mental status after each intervention Repeat fluid at 20 mL/kg if needed – Correct confirmed symptomatic severe hyponatremia with 3 mL/kg of 3% saline over 15 min – Administer lorazepam 0.05 mg/kg if patient actively having a seizure Monitor ongoing losses Check therapeutic end points in resuscitation – End-organ function – Heart rate, blood pressure, signs of perfusion – Mental status – Urinary output Monitor serum electrolytes, hypo/hypernatremia, acidosis, blood urea nitrogen/creatinine, glucose at least every 4-6 h
Effective Communication	Define team member roles and responsibilities Communicate effectively with other team members and pediatric ICU Promote collegial interaction and knowledge sharing

Table 16-10	Estimating Fluid Requirements
Body Weight	**Fluid**
<10 kg	100 mL/kg/day
11-20 kg	1000 mL + 50 mL/kg for each kg above 10 kg
>20 kg	1500 mL + 20 mL/kg for each kg above 20 kg

The method most widely used is the Holliday-Segar method, which relates caloric expenditure to body weight for a resting healthy patient. For every 100 calories expended, 100 mL of water is lost (65% urine + 35% insensible water) along with 2 to 4 mEq of sodium and potassium. Thus, a child weighing 25 kg would receive 1,600 mL

water daily (1,500 mL + 100 mL), 50 to 100 mmol of sodium each day, and 25 to 50 mmol of potassium daily. Unfortunately, this method underestimates electrolyte requirements in sick patients. Pediatric patients have been shown to develop hyponatremia when given hypotonic fluids in the hospital setting. The amount of dextrose required will depend on the patient's age and metabolic needs. Children who weigh <10 kg should receive a solution of 10% dextrose or higher. Those who weigh >10 kg typically require a 5% dextrose-containing solution. Dextrose solutions should be withheld in hyper-glycemic patients (glucose >180 mg/dL [9.9 mmol/ L]). The recommended solution for the patient weighing 25 kg would be 5% dextrose in normal saline with 20 mmol potassium chloride in each 1,000 mL (D5 0.9% sodium chloride + 20 mmol potassium chloride/L) or 5% Ringer lactate solution administered at 66 mL/h (1,600 mL/24 h).

Under normal conditions, maintenance fluid needs are derived from normal urine, stool, and insensible water losses. Stool water losses are usually negligible in patients without gastrointestinal abnormalities. Minimally acceptable urine output is ~2 mL/kg/h for a well-hydrated infant and 1 mL/kg/h for a child.



The higher ratio of surface area to body mass and the decreased subcutaneous fat reserves in infants and young children allow greater heat loss through evaporation and radiation. Maintenance of body temperature is also limited in infants because they have immature thermoregulatory control, cannot modify behavior (such as get a blanket), have large heads, have thin skin with lack of keratin, and have ineffective shivering due to immature muscles. The compensatory process of metabolizing brown adipose tissue to generate heat can be harmful because it results in metabolic acidosis. Hypothermia can also increase morbidity by impairing wound healing, increasing the risk of infection and apnea, and delaying metabolism. It is important, therefore, to maintain an appropriate, thermal-neutral environmental temperature to assure a rectal temperature of 37°C (98.6°F) in the neonate.

2. Glucose

Low glycogen stores and an increased metabolic rate make hypoglycemia common in infants during stress. A continuous infusion of glucose (5 mg/kg/min) is often necessary. If glucose-containing fluids are withheld, blood glucose should be monitored frequently (at least every 1-2 hours) to avoid hypoglycemia (glucose <65 mg/dL [3.6 mmol/L]). Boluses of 10% glucose (0.5-1 g/kg [5-10 mL/kg]) in neonates and 25% glucose (2-4 mL/kg) in children will generally correct hypoglycemia.

3. Sodium

Hyponatremia (sodium <135 mmol/L) is the most common metabolic abnormality found in the pediatric hospitalized patient. It occurs when hypotonic oral or intravenous solutions are given to children with increased losses secondary to diarrhea or diuretic use. Children with cystic fibrosis, adrenal insufficiency, syndrome of inappropriate antidiuretic hormone (SIADH), and obstructive uropathy are also at risk for hyponatremia. With severe hyponatremia (sodium <125 mmol/L), children exhibit signs of irritability, poor feeding, nausea and vomiting, lethargy, seizures, and eventually coma and death if left untreated. In those with hyponatremia-induced neurologic symptoms, 3% hypertonic saline can be titrated until seizures resolve, followed by a slow correction over 24 hours with an isotonic solution. The usual 3% sodium chloride (0.513 mmol/mL) dose is 3 mL/kg (2.5 mmol/kg). In patients with less severe acute hyponatremia (sodium 125-130 mmol/L), a slow correction over 12 to 24 hours to levels of about 130 mmol/L is recommended. The patient's hydration status must be considered when treating hyponatremia. Hypovolemic patients must be hydrated with normal saline. In euvolemic or hypervolemic patients with mild hyponatremia, fluid restriction and loop diuretics, in addition to the hyponatremia correction, might be indicated. Early consultation with a pediatric intensivist and transfer to a pediatric ICU for further monitoring are indicated in symptomatic patients.

Hypernatremia (sodium >145 mmol/L) results from excessive free-water losses in gastroenteritis, inadequate amounts of free-water intake, withholding of water, or nephrogenic or central diabetes insipidus. Infants are more susceptible to hypernatremia. Hypernatremic dehydration can be detected with signs such as irritability, high-pitched cry, mental status changes, hypertonia, and seizures. Isotonic fluids (normal saline) are recommended during the initial resuscitation phase to correct hypovolemia or shock. In children, the free-water deficit can be calculated as 4 mL/kg for every 1 mmol/L of sodium >145 mmol/L. The serum sodium should be lowered no faster than 0.5 mmol/L/h over 48 to 72 hours. Five percent dextrose half-strength normal saline (D5 0.45% sodium chloride) can be used in patients whose serum sodium is <165 mmol/L, allowing the sodium to drop no faster than 1 mmol/L/h. A more

conservative approach should be considered in patients with serum sodium >165 mmol/L; in these situations, the solution of choice may be dextrose 5% normal saline (D5 0.9% sodium chloride), provided an adequate hydration state was achieved. Central diabetes insipidus should be suspected in patients with brisk urine output after severe head injury or recent intracranial surgery. Early consultation with a pediatric neurosurgeon or pediatric intensivist is advised.

4. Potassium

Hypokalemia (potassium ≤3.5 mmol/L) is usually the consequence of renal losses (diuretic therapy), renal tubular disorder resulting from chemotherapy, gastrointestinal losses (vomiting, fistulas), or decreased intake. In children with life-threatening hypokalemia (arrhythmia, paralysis), potassium chloride can be administered intravenously at a rate of <1 mmol/kg/h (maximum 20 mmol/h) with continuous electrocardiographic monitoring. The usual replacement rate of potassium is 0.2 to 0.3 mmol/kg/h. Serum potassium levels must be monitored at frequent intervals during the replacement phase. Hyperkalemia (potassium >5.5 mmol/L) is most often the result of decreased losses, increased intake, or kidney dysfunction. Recommended treatment for hyperkalemia in children is outlined in **Table 16-11**.

Table 16-11 Treatment of Hyperkalemia

If significant electrocardiographic abnormalities are presented (peaked T waves, QRS widening, PR-interval prolongation:

- Administer calcium gluconate (10%) 50 mg/kg intravenously OR
- Administer calcium chloride (10%) 10 mg/kg intravenously via central line

For redistribution of potassium:

- Administer sodium bicarbonate 1 mmol/kg intravenously AND/OR
- Administer 25% dextrose 2-3 mL/kg (0.5-1 g/kg) + regular insulin 0.1 U/kg intravenously (1U for each 5 g dextrose)
- Administer inhaled β_2-agonist (albuterol 2.5-5 mg per dose has been used successfully)

To remove potassium:

- Administer loop diuretic: furosemide 0.5-1 mg/kg
- Administer sodium polystyrene sulfonate 1g/kg per dose orally/rectally every 6 h
- Perform dialysis

5. Calcium

Critically ill newborns are susceptible to hypocalcemia (total calcium <8.5 mg/dL [2.2 mmol/L], ionized calcium <1 mmol/L) because they experience a sudden withdrawal from the high rate of calcium intake associated with normal maternal-to-fetal transfer of calcium during gestation. In neonates with congenital heart disease, hypocalcemia may be the presenting sign for DiGeorge syndrome (22q11 microdeletion). Children with hypocalcemia may present with tetany, carpopedal spasm, laryngeal stridor, apnea, convulsions, hypotension, and congestive heart failure.

To correct life-threatening hypocalcemia in children, calcium gluconate (100 mg/kg per dose) should be injected through a small needle into a large vein at a rate of approximately 1.5 mL/min if central venous access is not available. Calcium chloride (20 mg/kg per dose) may be administered instead of calcium gluconate only if central venous access is available. Maintenance doses of calcium gluconate or calcium chloride may be delivered every 6 hours intravenously or by mouth (calcium gluconate 200-500 mg/kg/day) in cases of persistent hypocalcemia.

Hypercalcemia (total calcium >11 mg/dL [>2.75 mmol/L], ionized calcium >1.3 mmol/L) is rare in the pediatric population but suspicious for an underlying malignancy. Treatment is similar to that for adults: normal saline infusion of 10 to 20 mL/kg followed by furosemide administered 1 to 2 mg/kg every 6 to 12 hours.

6. Magnesium

Hypomagnesemia (magnesium <1.8 mg/dL or 1.5 mEq/dL [0.75 mmol/L]) is commonly associated with malnutrition or malabsorption syndromes in children with poor gut function and in critically ill infants receiving prolonged intravenous fluid administration. It can be seen in patients with a renal tubular disorder resulting from chemotherapy for the treatment of bone tumors. Clinical manifestations of hypomagnesemia overlap those of hypokalemia and hypocalcemia. Life-threatening hypomagnesemia may be treated with magnesium sulfate, giving 25 to 50 mg/kg intravenously over 5 to 15 minutes.

7. Phosphorus

Hypophosphatemia (phosphate <2.5 mg/dL [0.81 mmol/L]) is relatively uncommon in children and is usually associated with malnutrition, malabsorption syndromes, or renal tubular defects. Life-threatening hypophosphatemia, which may be signaled by muscle weakness, respiratory failure, coma, and seizures, can be treated with sodium phosphate or potassium phosphate as 0.4 mmol/kg infused over 6 hours (maximum 21 mmol).

D. Immune System

The following factors increase the risk of infection in neonates:

- Decreased polymorphonuclear white cell function and storage reservoir
- Reduced delivery of phagocytes to inflammatory sites
- Decreased antibody synthesis
- Passive maternal immunity that is depleted by 2 to 5 months after birth; immunoglobulin levels comparable to adult levels to adult levels are not reached until 4 to 7 years of age

Because of their incompletely developed immune systems, children are treated with empiric antibiotic therapy more frequently than are adults. For the same reason, antibiotics are considered an emergency drug, particularly for febrile infants younger than 2 months. Before the age of 3 years, the risk of occult bacteremia is increased if the temperature is >40°C (>104°F) or white blood cell count is <500 cells/mm^3 or >15,000 cells/mm^3. Absolute neutrophil count <1,000 cells/mm^3 or significant bands of 25% to 30% are also markers of severe bacterial infection in children. In such situations, a full workup is recommended and should include blood culture, urine culture, and lumbar puncture, if clinically indicated. The stages of physiologic compromise due to infection in pediatric patients are similar to adult stages of sepsis, with some modifications. The systemic manifestations of sepsis are age-adjusted for heart rate, blood pressure, and leukocyte count. Criteria for severe sepsis include cardiovascular dysfunction or acute respiratory distress syndrome or two or more other organ dysfunctions. Septic shock is defined by the presence of cardiovascular dysfunction.

In neonates, group B streptococci, *Escherichia coli*, *Listeria*, and *Enterococcus* often cause life-threatening bacterial infections. Organisms that should be considered in children ages 2 months to 2 years include *Streptococcus pneumoniae*, *Haemophilus influenzae*, *Neisseria meningitidis*, and *Salmonella*. The organisms associated with serious infections in children and the suggested treatments are summarized in **Table 16-12**.

Table 16-12 Most Common Serious Infections in Infants and Children

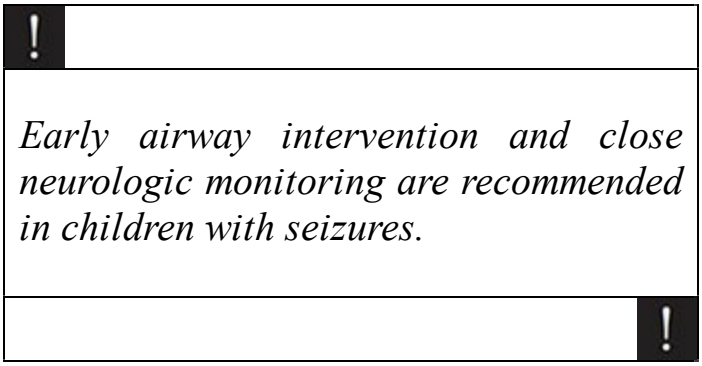
Site	Organism	Treatment[a]
Neonates		
Bacterial meningitis	Group B streptococci, *Escherichia coli* (and other enteric gram-negative organisms)	Cefotaxime 50 mg/kg/dose
	Listeria and *Enterococcus*	Ampicillin 50 mg/kg/dose

Viral meningitis	Neonatal HSV and HSV encephalitis	Acyclovir 15 mg/kg/dose
Children		
Bacterial meningitis	*Haemophilus influenzae, Streptococcus pneumoniae, Neisseria meningitidis, Salmonella*	Cefotaxime 50 mg/kg OR ceftriaxone 50 mg/kg; dexamethasone 0.15 mg/kg for *H influenzae* and *S pneumoniae*
Viral meningitis	HSV encephalitis	Acyclovir 15 mg/kg
Epiglottitis	*H influenzae*	Cefotaxime 50 mg/kg OR ceftriaxone 50 mg/kg
Bacterial tracheitis	*Staphylococcus, Streptococcus Moraxella catarrhalis*	Nafcillin 50 mg/kg/dose OR clindamycin 10 mg/kg/dose and cefotaxime 50 mg/kg/dose
Retropharyngeal abscess	*Staphylococcus aureus,* group A streptococci (may be mixed infection), gram-negative enteric organisms, anaerobes	Nafcillin 50 mg/kg OR clindamycin 10 mg/kg and gentamicin 2.5 mg/kg OR ampicillin/sulbactam 50-100 mg/kg (based on application) and gentamicin 2.5 mg/kg
Croup	Parainfluenza Influenza	Supportive care
Peritonitis	Gram-negative organisms: *E coli, Klebsiella* Gram-positive organisms: pneumococcus, *Staphylococcus*, α-hemolytic *Streptococcus*, *Enterococcus* Anaerobes: *Bacteroides*	Cefotaxime 50 mg/kg, clindamycin 10 mg/kg, and ampicillin 50 mg/kg OR ampicillin 50 mg/kg, gentamicin 2.5 mg/kg, and clindamycin or metronidazole 7.5 mg/kg
Immunocompromised patients	Gram-positive organisms: coagulase-negative *Staphylococcus*, α-hemolytic *Streptococcus, Enterococcus*, coryneform bacteria	Vancomycin 10-15 mg/kg
	Gram-negative organisms: *Klebsiella, Bacillus, Pseudomonas, E coli*	Cefepime 50 mg/kg OR ceftazidime 50 mg/kg
	Fungi: *Candida, Aspergillus*	Fluconazole: loading dose 10 mg/kg; maximum loading dose 400 mg Amphotericin B: 0.25-1 mg/kg/day OR caspofungin 50 mg/m^2/dose q24h; maximum dose 50 mg

Abbreviation: HSV, herpes simplex virus

[a]These recommendations are general guidelines only. Specific antibiotic choices should be individualized, taking into consideration clinical circumstances (renal function, liver function), patient age, immunization status, and local microbial virulence, sensitivities, and patterns of resistance. The antibiotic closing interval and frequency should be discussed with a pediatric intensivist or pediatric infectious disease expert.

The Glasgow Coma Scale is difficult to apply in children, even when it is adapted for age, as shown in **Table 16-13**. (See **Chapter 8** for its application to adults.) When assessing the need for further intervention, careful attention should be paid to the pupillary responses, the patient's ability to maintain the airway, the motor score, and the fontanelle fullness in infants. Any young child with a depressed level of consciousness, seizures, and/or coma should be evaluated for the possibility of occult trauma (eg, child abuse, especially shaken baby syndrome), even if there are no outward signs of injury. Infectious, metabolic, or toxic etiologies also should be considered. Boluses of 10% glucose in neonates and 25% glucose in children will generally correct hypoglycemia-induced coma and/or seizures (see earlier section). Hyponatremia, hypoglycemia, and hypocalcemia should be considered in small children with seizures. Diazepam may be administered rectally to children with ongoing seizure activity and no intravenous access (0.5 mg/kg per dose; use injectable or gel preparation). Lorazepam, midazolam, or diazepam can be used in the initial treatment of seizures at a dose of 0.05 to 0.1 mg/kg given intravenously. Subsequently, a full intravenous loading dose of phenytoin or fosphenytoin (15-20 mg/kg) should be administered if a second dose of benzodiazepine is ineffective. If the patient is already on phenytoin or the loading dose was ineffective, phenobarbital (15-20 mg/kg per dose) should be considered. Caregivers should be aware of the cumulative respiratory depression potential of these medications and the resulting need for early airway support. Endotracheal intubation and general anesthesia should be considered in the event that seizures persist despite adequate treatment. Neuromuscular blocking agents are used only to facilitate endotracheal intubation. Early consultation with a pediatric neurologist and pediatric intensivist is recommended.



The unique features in the care of infants and children highlight the very small margin for error in treating critically ill or injured pediatric patients. Specialty consultation should be requested early.

Table 16-13	Glasgow Coma Scale Modified for Infants and Children

Clinical Parameter	Infants (ages 0-12 months)	Children (ages 1-5 years)	Points[a]
Eye Opening	Spontaneous	Spontaneous	4
	Response to speech	Response to speech	3
	Response to pain	Response to pain	2
	No response	No response	1
Verbal Response	Coos/babbles	Appropriate words	5
	Irritable cries	Inappropriate words	4
	Cries	Persistent cry	3
	Moans	Grunts	2
	No response	No response	1
Best Motor Response	Normal	Spontaneous	6
	Withdraws to touch	Localized pain	5
	Withdraws from pain	Withdraws from pain	4
	Flexor response	Flexor response	3
	Extensor response	Extensor response	2
	No response	No response	1

[a]Total Glasgow Coma Scale score = eye + verbal + motor points; best possible score = 15; worst possible score = 3

Key Points

Critical Care in Infants and Children: The Basics

- Irritability is an early sign of changes in mental status in the young child.
- In children, early signs of respiratory distress include tachypnea, grunting, and nasal flaring.
- Ensuring a patent airway is the most important initial step in treating a child with respiratory compromise.
- Important airway anatomic differences between a child and an adult must be considered when intubating an infant or child.
- Suggested initial ventilator settings for children are tidal volume, 6 to 10 mL/kg in

normal lungs, 6 mL/kg in acute lung injury or acute respiratory distress syndrome. Respiratory rates in children may need to be higher than those in adults to maintain acceptable $Paco_2$ levels.

- The perfusion status in children is best assessed initially by capillary refill and extremity temperature. Hypotension is a late finding in children with shock. Those with hypovolemic shock may require 40 to 60 mL/kg of isotonic fluids (normal saline, Ringer lactate solution).
- Vasopressor support with norepinephrine is indicated in patients with fluid-refractory vasodilated shock. Dopamine is indicated for low cardiac output (vasoconstricted shock) after adequate fluid resuscitation is delivered.
- Obstructive shock in infants is commonly caused by congenital lesions that interfere with outflow from the left ventricle, such as coarctation of the aorta or interrupted aortic arch.
- Intracranial hemorrhage in the young infant can cause hemodynamically significant blood loss.
- Hypoglycemia is common in infants during stress and must be corrected promptly.
- Infants do not maintain body temperature well, and care must be taken to avoid hypothermia.
- Young infants are at increased risk of infection due to their immature immune systems.
- Empiric antibiotics are considered an emergency drug for febrile infants younger than 2 months.
- Diazepam may be administered rectally to children with ongoing seizure activity who have no intravenous access.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Brierley J, Carcillo JA, Choong K, et al. Clinical practice parameters for hemodynamic support of pediatric and neonatal septic shock: 2007 update from the

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Suggested Website

1. *Society of Critical Care Medicine/Guidelines. www.sccm.org*

RAPID RESPONSE SYSTEM

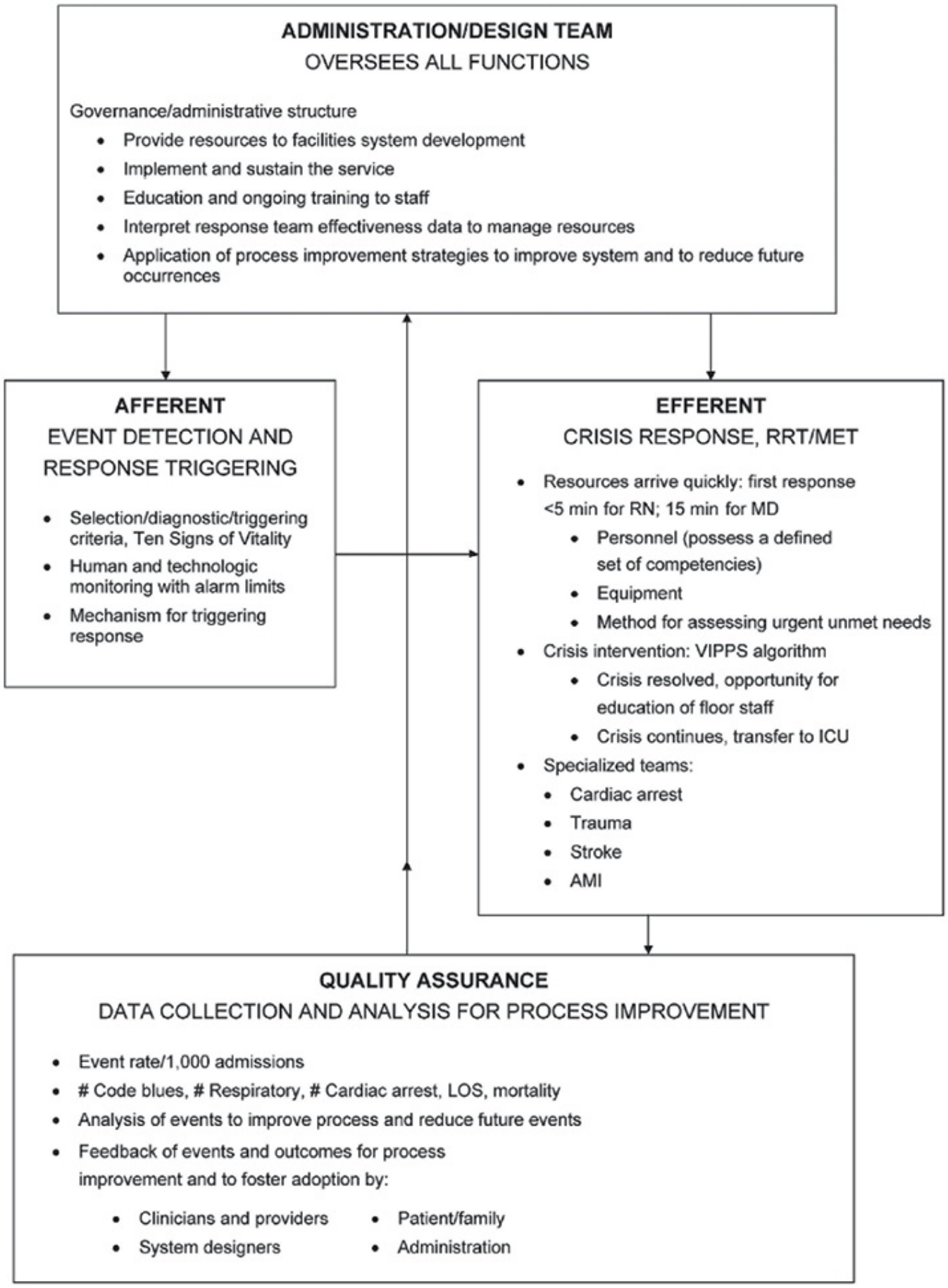
I. INTRODUCTION

Rapid response systems (RRS) have emerged as important resources that focus on the hospitalized patient with unexpected, sudden deterioration in a condition from any cause. Historically, crisis teams were activated only after a significant event, such as cardiac arrest; there was no organized approach to preventing an untoward event in an at-risk hospitalized patient. Most patients who have a cardiac arrest while in the hospital demonstrate identifiable signs of deterioration in the previous 8 hours. Early recognition of deterioration and timely intervention can reduce the incidence of in-hospital cardiac arrest or need for intensive care. Rapid response systems have been shown to reduce in-hospital mortality and cardiopulmonary arrest, although the presence of a physician is not significantly associated with a mortality reduction.

Unfortunately, the early indicators of clinical deterioration can be difficult to identify. Assessing a patient's physiologic reserve is challenging. Rapid response systems bring additional experienced providers with advanced monitoring tools to the patient's bedside. If needed, more advanced monitoring and therapy can be initiated immediately, and a decision can be made about the most appropriate care level. The most important action in the process is the call for help.

The RRS model can be divided into four components, each of which plays an integral role in the success of the system (**Figure A1-1**). The administrative arm oversees appropriate staffing, provides resources, drafts protocols and guidelines, and ensures staff education regarding the presence and utility of the service. The afferent arm is concerned with detecting impending deterioration, while the efferent arm is focused on rendering therapy and mobilizing additional resources quickly. Lastly, the performance improvement arm seeks to identify recurrent patterns of deterioration and assess improvement in quality measures following system-wide interventions.

Figure A1-1. Rapid Response System Structure



Abbreviations: RRT, rapid response team; MET, medical emergency team; RN, nurse; MD, physician; VIPPS, ventilation, infusion of volume, pressors/pump, pharmacy, and specific interventions; AMI, acute myocardial infarction; LOS, length of stay

[a]Adapted from Sebat F, ed. *Designing, Implementing, and Enhancing a Rapid Response System*. Mount Prospect, IL: Society of Critical Care Medicine; 2009:41.

II. BUILDING A MEDICAL EMERGENCY OR RAPID RESPONSE TEAM

Rapid response teams represent an intuitively simple concept: When a patient demonstrates signs of imminent clinical deterioration, a team of providers is summoned to the bedside to immediately assess and treat the patient with the goal of preventing transfer to the ICU, cardiac arrest, or death. A rapid response team (RRT) is the intervention limb of the RRS. By consensus, a medical emergency team (MET) is led by a prescribing clinician (physician or advanced practice provider), whereas an RRT is a led by a nurse and/or respiratory therapist (nonprescribing clinician). However, most recently, these two terms have been used interchangeably.

A. Response Team Composition

Although there is no single perfect team composition, the most successful METs and RRTs have been developed by leveraging existing hospital resources and targeting particular at-risk patient populations. Multidisciplinary, physician-led teams (METs) are prevalent in academic centers with training programs. Nurse-led or nurse–respiratory therapist teams (RRTs) with physician backup (or medical control similar to the emergency medical services model) are more often found in community hospitals without training programs. Regardless of the team composition, effective teamwork skills are essential to the success of the program. The implementation of standardized protocols or standing orders allows the team to use evidence-based best practices to address commonly identified clinical issues. The RRS administrative leadership should develop these protocols and standing orders in accordance with institutional policies and procedures. Possible members of an MET or RRT are identified in **Table A1-1**.

Table A1-1	Possible Members of Medical Emergency or Rapid Response Team
Physicians (attending, fellow, resident)	Intensivist, hospitalist, emergency medicine physician, anesthesiologist, pulmonologist, surgeon, internist
Advanced practice	Nurse practitioner, physician assistant

providers	
Nurses	ICU nurse, postanesthesia care unit nurse, emergency department nurse, telemetry unit nurse, certified registered nurse anesthetist, nursing supervisor
Other providers	Respiratory therapist, electrocardiography technician, emergency medical technician/paramedic

At an academic hospital, the composition of the responding team may include the following combinations of caregivers:

- ICU attending and/or fellow, ICU nurse, respiratory therapist, pharmacist
- Hospitalist, medicine resident or advanced practice provider, ICU nurse, respiratory therapist
- ICU nurse, respiratory therapist, physician (backup)

At a non-teaching hospital, the team may consist of one of the following combinations:

- Emergency department physician or advanced practice provider, hospitalist, ICU nurse, respiratory therapist
- Emergency department nurse, ICU nurse, respiratory therapist
- Postanesthesia care unit nurse, respiratory therapist, physician (backup)

Typically, physician members are trained (or are training) in critical care, emergency medicine, anesthesia, or internal medicine. They bring their knowledge of critical illness and their skills in the management of life-threatening problems to the patient's bedside. Nurse members usually have many years of bedside experience and most often have extensive critical care training. Team members from other disciplines add value to the MET or RRT with their knowledge of such factors as airway and respiratory management, drug therapies, traumatic injury management, and critical care transport.

Team members usually are expected to maintain current provider status in basic and advanced cardiac life support, pediatric advanced life support (where applicable), and fundamental critical care. Periodic teamwork exercises in mock events or medical simulation centers can hone members' evaluation and management skills. Treatment protocols and standing orders should be reviewed and amended based on feedback from MET or RRT calls and quality improvement data.

B. Response Team Equipment

The use of advanced physiologic monitors and equipment by appropriately trained MET members can provide crucial support to the at-risk patient. This can greatly enhance the team's ability to evaluate and manage signs and symptoms of clinical deterioration. Clearly, the earlier clinical abnormalities are identified and addressed, the greater the potential for a positive outcome and, often, the simpler the needed intervention. The MET or RRT should first evaluate the resources that are readily available in the areas it will support and then create a list of additional needed equipment (**Table A1-2**). The response team must have access to cardiac, respiratory, and simple hemodynamic monitors. Other equipment and medications should be selected based on the patient populations served, the team composition, and local regulations and policies. Since the MET or RRT is expected to respond quickly, any additional necessary equipment and supplies should be organized in appropriate bags or carts that can be readily transported to the patient.

Table A1-2 Response Team Equipment List[a]

Physiologic Monitors	**Cardiovascular Equipment**
Monitor/defibrillator with external pacing capability	Manual blood pressure device
Noninvasive blood pressure device	IV administration kits
Pulse oximetry	IV catheters
Portable capnography (if available)	
	Miscellaneous
Respiratory Equipment	Personal protective equipment
Portable oxygen tank	Sterile gloves
Portable suction device	Dressings and bandages
High-flow oxygen reservoir face mask	Antiseptics
Bag-mask device	Drug Bag (as appropriate for scope of practice)
Ventimask®, nasal cannula, and simple face mask	Vasopressors
Nebulizer mask	Inotropes
Oropharyngeal/nasopharyngeal airways	Vasodilators
Laryngeal mask airways	Sedatives and analgesics
Laryngoscopes and blades	Bronchodilators
Endotracheal tubes with stylets	Crystalloid and colloid IV fluid
Cricothyrotomy catheter kit	Aspirin
Stethoscope	
Consider portable ultrasound machine where available	

[a]Necessary equipment and supplies should be available on the patient unit or carried by the team.

III. ACTIVATING THE MEDICAL EMERGENCY OR RAPID RESPONSE TEAM

A. Activation Criteria and Triggers

The most important activation criterion is the concern of the bedside physician, nursing staff, or family that something is wrong, even if other indicators are within acceptable limits. This intuition is often quite sensitive and warrants additional assessment. The fact that an intuition or a gut feeling is not very specific should not discourage activation of the MET or RRT.

The distribution of a predefined set of MET or RRT activation criteria may help to focus attention on important early indicators and empower the bedside staff to call for help early. These criteria may be based on the detection of acute changes in physiology, organ system–specific signs and symptoms, and event triggers (**Table A1-3**). Acute changes in physiology may include changes in vital signs that exceed predefined limits, like tachycardia, tachypnea, hypotension, and oliguria. The detection of one or more indicators of organ system dysfunction may trigger activation of the response team. Such pattern recognition may be more effective in detecting clinical deterioration when there is a gradual change in physiologic variables.

Table A1-3 Models of Activation Criteria

Acute Physiologic Criteria
Acute Physiologic Criteria
Acute change in heart rate to <40 or >130 beats/min
Acute change in systolic blood pressure to <90 mm Hg
Acute change in urine output to <50 mL in 4 hours
Acute change in respiratory rate <8 or >30 breaths/min
Acute change in pulse oximetry to <90% despite oxygen administration
Acute change in consciousness
Qualitative deterioration in clinical status

Organ System-Specific Criteria
Airway
- Respiratory distress
- Threatened airway

Breathing

Respiratory rate >30 breaths/min
Respiratory rate <6 breaths/min
Sp_{O_2} <90% on oxygen
Difficulty speaking

Circulation
Blood pressure <90 mm Hg despite treatment
Pulse rate >130 beats/min

Neurology
Any unexplained decrease in consciousness
New agitation or delirium
Repeated or prolonged seizures

Other
Concern about the patient
Uncontrolled pain
Failure to respond to treatment
Inability to obtain prompt assistance

Event Trigger
Unscheduled naloxone dose administered
Increase in oxygen requirement
Any change to a 100% reservoir face mask
Any change in F_{IO_2} delivery by ≥20%
After 3 unanswered pages to medical/surgical team for any patient in a shift
Response time to medical/surgical team page >30 min
Family concern about patient status
Any falls or traumatic injuries
Pain score ≥4 of 10 more than 30 min after highest ordered dose of analgesic
Persistent nausea/vomiting more than 30 min after highest dose of antiemetic
Any newly noted abnormal pulse

Abbreviations: Sp_{O_2}, oxygen saturation on pulse oximetry; F_{IO_2}, fraction of inspired oxygen.

Event triggers help emphasize that some patient incidents or interventions warrant further evaluation. The event may be a sign or a result of a larger issue that could be an ongoing threat to the patient's safety. For example, any administration of naloxone is an indicator that one or more undesirable side effects of opiates may be present. Although naloxone may temporarily reverse these side effects, they can recur as the antagonist effects wane. A focused evaluation by the MET or RRT may avoid the undesirable consequences of these events.

B. Response Team Scoring Systems

The use of a scoring system in evaluating the at-risk patient can provide a graded assessment of clinical status and help to determine the level of response needed. An overall score is calculated based on the aggregate of points assigned to various symptoms, vital signs, and laboratory studies. Additional points are assigned to results

that vary greatly from normal. Several patented early warning scoring systems are available, although not all are validated. The Modified Early Warning Score, which evaluates a patient's vital signs and mental status, has been validated in hospitalized medical patients. A score of 5 or greater has been associated with an increased mortality rate and increased incidence of ICU admission.

Individual MET or RRT programs may choose to define absolute value or trend thresholds that trigger a move to a higher level of care or mobilization of additional clinical resources. Collection and analysis of aggregate scores in patients receiving MET or RRT services can be used for quality improvement efforts, such as evaluation of standing orders, event cluster identification, and resource utilization.

IV. TEAM RESPONSE

A. Response Team Interventions

Interventions should be aimed at rapidly stabilizing the patient and preventing further deterioration or full arrest. Studies have shown that the ***three most common reasons for activating an MET or RRT are hypoxemia, hypotension, and altered mental status***. Teams should identify the primary activating events in their institutions and build protocols to address each rapidly.

Respiratory distress is the leading physiologic cause of MET or RRT activation. The reasons for acute changes can be related to fluid status, medications (eg, narcotics), progression of underlying disease, or patient noncompliance with physician-ordered oxygen therapies. Initial treatment is stabilization of the airway and application of high-flow oxygen to relieve the patient's distress and improve oxygen saturation. Following improvement in patient status, the team can evaluate for potential reversible causes.

Hypotension can be related to volume status (both overall volume and blood volume); medications, including narcotics and antihypertensives; and the potential for sepsis. Initial treatment is administration of fluids to raise systolic pressure and/or the immediate reversal of a known cause, such as narcotics. Consideration should be given to empiric antibiotic therapy in cases of suspected severe sepsis or septic shock.

Altered mental status is most often associated with hypoxemia, hypotension, or hypoglycemia. These should be evaluated and treated first. Altered mental status unrelated to those issues should be evaluated for either neurologic or medication causes. Treatment, including evaluation with computed tomography scanning, should be

guided accordingly.

The responding team should make every effort to involve the patient's primary physician and rounding team in decisions regarding disposition and care. The role of a MET or RRT is not to take the place of the primary team but to act for – and with – them at the bedside in an emergency.

B. Response Team Communications

In the complex hospital environment, the use of a structured communication tool and a common critical language fosters the open communication among caregivers that is essential to the prompt evaluation and management of the at-risk patient. Incorporating the Situation, Background, Assessment, and Recommendation (SBAR) Tool into MET or RRT documentation can facilitate effective communication by gathering all pertinent data in one place for any discussions to follow. This tool has proven to be most valuable in the effective communication of critical information (**Table A1-4**).

Table A1-4	SBAR Communication Tool
Situation: *What is happening with the patient?*	
Background: *What is the clinical background or context?*	
Assessment: *What do I think is the problem?*	
Recommendation/interventions: *What would I do to evaluate or correct it?*	

C. Response Team Education

One of the primary goals of METs and RRTs is education. The detection limb of the RRS model relies heavily on the early recognition of signs and symptoms of clinical deterioration. Regularly scheduled staff in-services and mock-event drills are effective in maintaining competencies in identifying the at-risk patient. Public posting and discussion of activation criteria can further enhance the use of MET or RRT services and reduce patient clinical crises. Review of aggregate quality improvement data from response team activity also can reinforce education. Post hoc review of a patient event with the entire unit staff after an MET or RRT call serves to raise the entire group's collective knowledge and skill. This may reduce the likelihood of subsequent problems and increase the likelihood that signs and symptoms of clinical deterioration will be detected at the earliest indication in future patients. Topic-of-the-week presentations, MET or RRT case reviews, and SBAR practice sessions are examples of targeted

educational activities.

V. STRATEGIES FOR SUCCESS

Hospitals that use an RRS report various factors that lead to successful team implementation. Some common themes in their success include:

1. Training/Education – The MET or RRT members and the bedside nursing staff must understand when and how to activate the team and the scope of team capabilities. The response team members will need ongoing training in management of common indicators in at-risk patients and effective intervention and communication strategies. The mentoring of the bedside nursing staff in critical assessment skills and effective communication skills is a primary team education objective. High-fidelity simulation in a simulation center is helpful, but low-fidelity simulations with mock medical emergency scenarios or table-top exercises are effective as well. Scenario-based case presentations using a chalkboard or paper can be offered in any clinical setting.

2. Equipment/Supplies – The equipment and supplies carried by the response team should be tailored to the needs of the patient population served, but then standardized to assure that the appropriate resources reach the bedside with each call. If multiple RRT bags are used, the items should be organized within each bag to facilitate rapid access at the bedside. It is impractical to carry every item available in the ICU. Equipment use should be reviewed as part of the quality improvement program. Seldom-used items should be removed unless they serve an important role in the management of infrequent, but high-risk events. The response team should strive to carry only the necessary equipment and supplies.

3. Culture of Empowerment – Staff nurses should be trained to recognize signs of clinical deterioration before a crisis and to trust their experience and skills. They should be empowered, and supported by leadership, to activate the MET or RRT according to established criteria. There should be no penalty for activating the MET or RRT, especially if the findings do not point to an impending clinical crisis. Such events can identify areas for targeted education in the detection of signs of clinical deterioration or focused review of the risks inherent to that patient population.

4. Evaluation – Data collection should be embedded into the clinical workflow to facilitate monitoring of clinical and service outcomes. Regular reporting, monitoring, and evaluation of response team activities and outcomes guide rapid

cycle improvement of team processes. Patient and family satisfaction data help prioritize program development and resource allocation. Constant dialogue among the stakeholders to identify improvement opportunities is essential.

VI. SUMMARY

Hospitalized patients can be at risk for clinical deterioration in part due to the complex nature of healthcare delivery systems. The goal of the RRS model is to identify and manage signs and symptoms of clinical deterioration in at-risk patients through detection strategies at the bedside and mobilization of appropriate resources. Important factors in the successful implementation of an RRS include: (1) appropriate team composition; (2) activation criteria based on bedside staff concern, acute changes in physiology, or the use of scoring systems to identify at-risk patients; (3) interventions aimed at rapidly stabilizing the patient; (4) effective communication strategies like SBAR; (5) ongoing education to enhance detection and management of potential clinical crises; (6) availability of appropriate advanced clinical monitors, equipment, and medications to conduct MET or RRT activities; and (7) evaluation and correction of processes and causes of patient risk.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

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11. Subbe CP, Kruger M, Rutherford P, Gemmel L. Validation of a modified Early Warning Score in medical admissions. *QJM*. 2001;94:521-526.

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Suggested Website

1. American College of Cardiology. http://www.acc.org.

AIRWAY ADJUNCTS

I. LARYNGEAL MASK AIRWAY

A. Indications

1. Provide an airway and ventilation when bag-mask ventilation is difficult
2. Provide a temporizing airway when endotracheal intubation is unsuccessful

B. Equipment

1. Bag-mask resuscitation unit with high-flow oxygen source
2. Pulse oximeter
3. Electrocardiographic monitor
4. Blood pressure monitoring
5. Gloves, mask, eye protection
6. Laryngeal mask airway (LMA) of appropriate size (**Table A2-1**)
7. Syringe for cuff inflation
8. Water-soluble lubricant
9. Qualitative CO_2 detector or CO_2 monitor
10. Resuscitation cart

Table A2-1 Laryngeal Mask Airway Size and Cuff Inflation

LMA Size	Patient Size	Maximum Cuff Volume	Largest ETT ID (mm)[a]
1	Neonate/infant to 5 kg	Up to 4 mL	3.5
1.5	5-10 kg	Up to 7 mL	4.0
2	10-20 kg	Up to 10 mL	4.5

2.5	20-30 kg	Up to 14 mL	5.0
3	>30 kg/small adult	Up to 20 mL	6.0 cuffed
4	Average adult	Up to 30 mL	6.0 cuffed
5	Large adult	Up to 40 mL	7.0 cuffed

[a]Largest endotracheal tube size (ETT ID) that will fit through laryngeal mask airway (LMA) tube lumen.

C. Preparation for insertion

1. Don gloves, mask, and eye protection.
2. Assure patent airway and optimal oxygenation and ventilation.
3. Assure intravenous access.
4. Apply pulse oximeter, electrocardiographic and blood pressure monitors.
5. Select appropriate size LMA.
6. Check cuff integrity by inflating and fully deflating.
7. Lubricate only the posterior aspect of the deflated mask with a water-based lubricant.
8. Preoxygenate with 100% oxygen for 2 to 3 minutes if time permits.

D. Technique (**Figure A2-1**)

1. The cuff is deflated completely so that it forms a spoon shape and there are no folds in the mask.
2. The operator stands behind the head of the bed, and the bed is raised to a position of comfort for the operator.
3. The patient is placed in the sniffing position (ie, head extended, neck flexed), unless potential or definite cervical spine injury prevents neck extension.
4. Cricoid pressure is not recommended during placement of the LMA because it may interfere with correct placement.
5. The mask is positioned with the bowl facing anteriorly. Hold the device like a pencil, with the index finger of the dominant hand at the junction of the bowl and tube, pressing against the palate and pharyngeal wall with the index finger.
6. The cuff is inserted into the hypopharynx until definite resistance is felt.

7. Without the operator holding the device, the cuff is inflated with enough air to obtain a seal around the laryngeal inlet. This results in an outward movement of the tube.

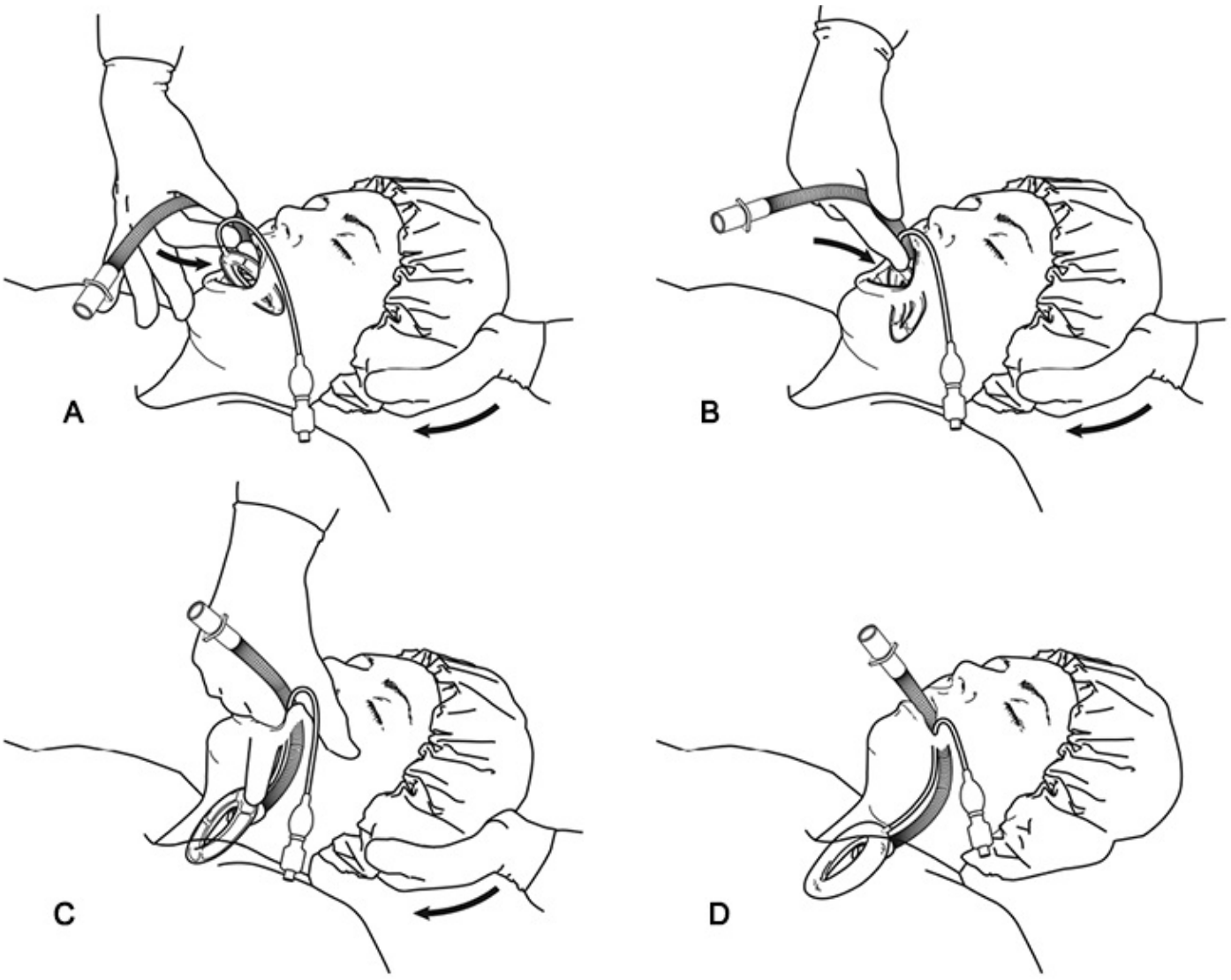
8. The cuff is inflated with enough air to obtain a seal (intracuff pressure of approximately 60 cm H_2O). Maximum volumes are listed in **Table A2-1**, but lesser volume may provide an adequate seal.

9. A manual ventilation device is attached, and chest movement and breath sounds are verified in both lung fields. Correct position should be confirmed with a qualitative or quantitative end-tidal CO_2 detector.

10. If chest movement is inadequate, or if a large air leak is present, the device should be removed and reinserted.

11. When the LMA is positioned appropriately, the tube is secured with tape.

Figure A2-1. Insertion Technique for Laryngeal Mask Airway



(A) Insert lubricated and deflated mask into the open mouth with the bowl facing anteriorly. **(B)** Hold the device like a pencil, pressing against the palate and pharyngeal wall with the index finger. **(C)** Continue inserting the cuff behind the tongue into the hypopharynx until definite resistance is felt. **(D)** Without holding the device, inflate cuff with enough air to obtain a seal. Attach manual ventilation device and ensure chest movement.

II. ESOPHAGEAL-TRACHEAL DOUBLE-LUMEN AIRWAY DEVICE

A. Indications

1. Cardiorespiratory arrest and inability to provide an airway by other means

B. Equipment

1. Bag-mask resuscitation unit with high-flow oxygen source

2. Pulse oximeter
3. Electrocardiographic monitor
4. Blood pressure monitoring
5. Gloves, mask, eye protection
6. Esophageal-tracheal double-lumen device
7. Syringe for cuff inflation
8. Water-soluble lubricant
9. Qualitative CO_2 detector or CO_2 monitor
10. Resuscitation cart

C. Preparation for insertion

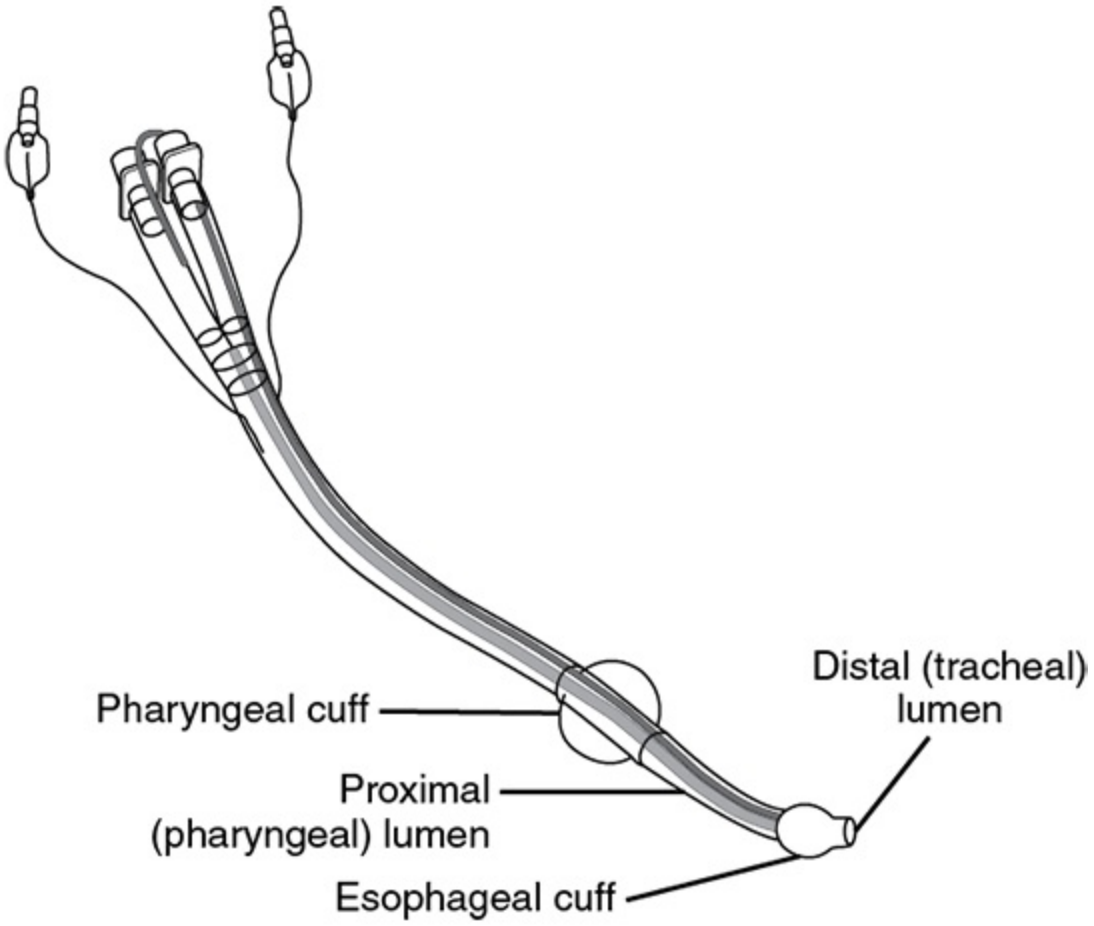
1. Don gloves, mask, and eye protection.
2. Assure patent airway and optimal oxygenation and ventilation.
3. Assure intravenous access.
4. Apply pulse oximeter, electrocardiographic and blood pressure monitors.
5. Select appropriate size device. The available sizes for the device are 41 and 37 French. Use the 41 French for patients taller than 5 feet (152 cm) and the 37 French for patients less than that height.
6. Check integrity of both cuffs by inflating and fully deflating.
7. Preoxygenate with 100% oxygen for 2 to 3 minutes if time permits.

D. Technique (**Figure A2-2**)

1. The cuffs should be deflated completely.
2. The operator stands behind the head of the bed, and the bed is raised to a position of comfort for the operator.
3. The patient is placed in a neutral or sniffing position (ie, head extended, neck flexed), unless potential or definite cervical spine injury prevents neck extension.

4. The patient's tongue and jaw are grasped between the thumb and index finger, and the device is inserted blindly. It is advanced until the placement ring markers on the tube are positioned as indicated by the manufacturer. Do not force the tube if resistance is met. A laryngoscope can be used to assist with placement.

Figure A2-2. Esophageal-Tracheal Double-Lumen Airway Device



Some tubes have two pilot balloons to allow for independent inflation of the pharyngeal and esophageal cuffs, whereas other tubes have a single pilot port and simultaneously inflate both cuffs. Detection of end-tidal CO_2 in the proximal lumen suggests that the tube is in the esophagus. In the rare instance that the tube enters the trachea, ventilation is only possible via the distal lumen and end-tidal CO_2 will not be detected from the proximal lumen.

5. The pharyngeal cuff is inflated first to seal the posterior pharynx.
6. The distal cuff is then inflated.
7. Ventilation should be attempted first through the pharyngeal lumen, and the chest should be auscultated for breath sounds and observed for movement. The tube enters the esophagus approximately 95% of the time.

8. If breath sounds are absent, ventilation should be attempted through the tracheal lumen while auscultating for breath sounds.
9. Use of the correct lumen for ventilation should be confirmed with a qualitative/quantitative end-tidal CO_2 or esophageal detector device.
10. When the device is positioned appropriately, the tube is secured with tape.

III. VIDEO LARYNGOSCOPE

A. Indications

1. Endotracheal intubation in known or presumed difficult airway
2. Known or suspected cervical spine injury

B. Equipment

1. Bag-mask resuscitation unit with high-flow oxygen source
2. Pulse oximeter
3. Electrocardiographic monitor
4. Blood pressure monitoring
5. Gloves, mask, eye protection
6. Video laryngoscope with appropriate blade
7. Endotracheal tube (ETT) of appropriate size for patient
8. Syringe for cuff inflation
9. Water-soluble lubricant
10. Qualitative CO_2 detector or CO_2 monitor
11. Resuscitation cart

C. Preparation for insertion

1. Don gloves, mask, and eye protection.

2. Assure patent airway and optimal oxygenation and ventilation.
3. Assure intravenous access.
4. Apply pulse oximeter, electrocardiographic and blood pressure monitors.
5. Prepare ETT with stylet and check cuff.
6. Turn on video laryngoscope power and check light/camera.
7. Assure proper cable and blade attachment.
8. Position video screen for optimal viewing during laryngoscopy.
9. Preoxygenate with 100% oxygen for 2 to 3 minutes if time permits.

D. Technique (**Figure A2-3**)

1. The operator stands behind the head of the bed, and the bed is raised to a position of comfort for the operator.
2. The patient is placed in a neutral or sniffing position (ie, head extended, neck flexed), unless potential or definite cervical spine injury prevents neck extension.
3. Consider lubricating the tongue side of the laryngoscope blade prior to insertion. Insert the laryngoscope blade into the oropharynx, and advance into the hypopharynx while watching the video screen for anatomical landmarks.
4. Once positioned in the hypopharynx, lift up and away, then adjust the position until the glottis and vocal cords are seen.
5. Insert and advance the ETT into the hypopharynx until the tip is seen near the end of the laryngoscope blade.
6. Advance the ETT through the glottis opening until the cuff passes the vocal cords. Make small adjustments in laryngoscope and ETT positioning as necessary to intubate the trachea.
7. Gently remove the laryngoscope blade while holding the ETT in place. Be careful not to kink or pinch the camera cable.
8. Inflate the ETT cuff and remove the stylet. Attach the bag-valve device and provide manual ventilation. Confirm bilateral breath sounds and end-tidal carbon dioxide.

9. When the ETT is positioned appropriately, the tube is secured with tape.

Figure A2-3. Video Laryngoscope[a]

IV. OPTICAL LARYNGOSCOPE

A. Indications

1. Endotracheal intubation in known or presumed difficult airway
2. Known or suspected cervical spine injury

B. Equipment

1. Bag-mask resuscitation unit with high-flow oxygen source
2. Pulse oximeter
3. Electrocardiographic monitor
4. Blood pressure monitoring
5. Gloves, mask, eye protection

6. Appropriately sized optical laryngoscope – color coded
7. ETT of appropriate size for patient
8. Syringe for cuff inflation
9. Water-soluble lubricant
10. Qualitative CO_2 detector or CO_2 monitor
11. Resuscitation cart

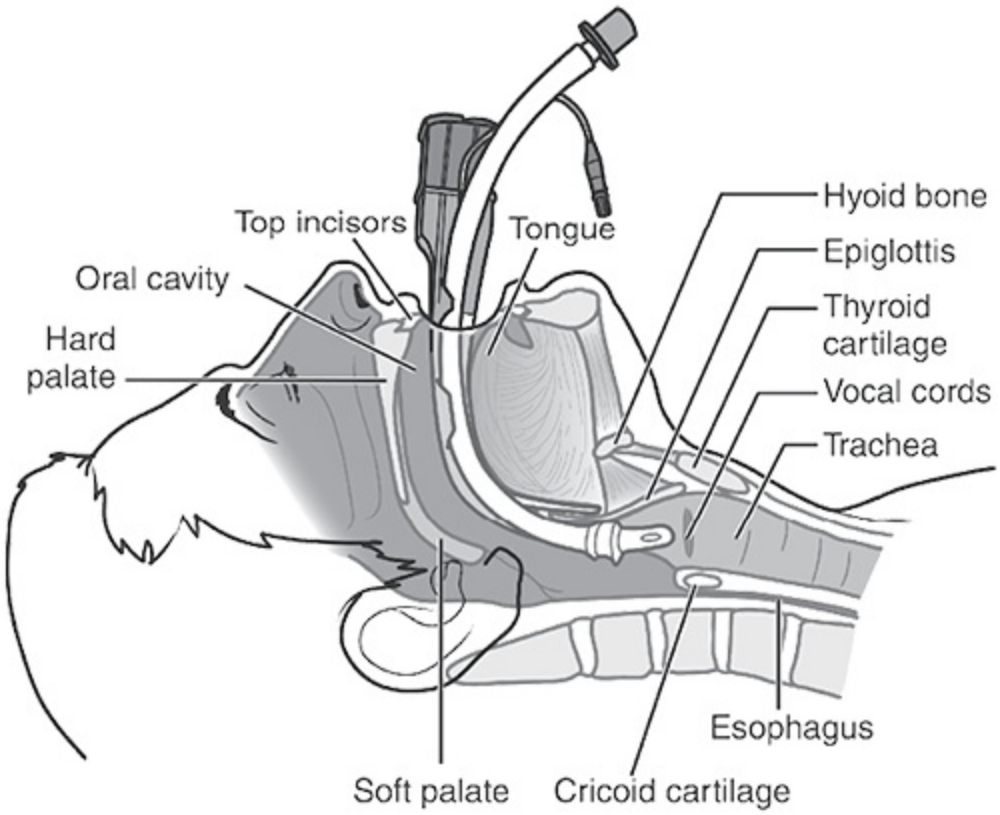
C. Preparation for insertion

1. Don gloves, mask, eye protection.
2. Assure patent airway and optimal oxygenation and ventilation.
3. Assure intravenous access.
4. Apply pulse oximeter, electrocardiographic and blood pressure monitors.
5. Prepare ETT, check cuff, and lubricate.
6. Choose appropriately sized optical laryngoscope.
7. Turn on laryngoscope light at least 30 seconds prior to use.
8. Load ETT into optical laryngoscope side channel.
9. Assure ETT tip is seen through eyepiece but is not obstructing view.
10. Preoxygenate with 100% oxygen for 2 to 3 minutes if time permits.

D. Technique (**Figure A2-4**)

1. The operator stands behind the head of the bed, and the bed is raised to a position of comfort for the operator.
2. The patient is placed in a neutral or sniffing position (ie, head extended, neck flexed), unless potential or definite cervical spine injury prevents neck extension.

Figure A2-4. Optical Laryngoscope



The optical laryngoscope allows the operator to look through the device, whereas the video laryngoscope in **Figure A2-3** is the device with the video camera and screen.

3. Consider lubricating the tongue side of the laryngoscope blade prior to insertion. Insert the laryngoscope blade in the midline over the tongue into the oropharynx and advance into the hypopharynx by rotating the laryngoscope along the tongue until it is perpendicular. Use caution to not displace the tongue posteriorly.

4. Once positioned in the hypopharynx, look through the eyepiece and lift up gently. Adjust the position until the glottis and vocal cords are seen. If glottis structures are not seen, gently pull back until seen. DO NOT tilt back or leverage against upper teeth or gums.

5. Advance the ETT through the glottis opening until the cuff passes the vocal cords. Make small adjustments in laryngoscope positioning as necessary to intubate the trachea.

6. Inflate the ETT cuff and separate from the laryngoscope with a gentle spreading or peeling motion. Be careful to not displace the ETT.

7. Gently remove the laryngoscope blade while holding the ETT in place. Rotate in opposite direction from insertion.

8. Attach the bag-valve device and provide manual ventilation. Confirm bilateral breath sounds and end-tidal carbon dioxide.

9. When the ETT is positioned appropriately, the tube is secured with tape.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Brain AIJ. *The Intavent Laryngeal Mask Instruction Manual*. Berkshire, UK: Brain Medical; 1992.

2. Danks RR, Danks B. Laryngeal mask airway: review of indications and use. *J Emerg Nurs*. 2004;30:30-35.

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ENDOTRACHEAL INTUBATION

I. INDICATIONS, PATIENT EVALUATION, MANUAL MASK VENTILATION, PATIENT PREPARATION

See Chapter 2.

II. EQUIPMENT

A. Bag-mask resuscitation unit with oxygen supplementation (with positive end-expiratory pressure valve if indicated)

B. Topical anesthetic spray

C. Medications as selected for analgesia/anesthesia, amnesia, and neuromuscular blockade

D. Towel roll or pad for occipital elevation

E. Pulse oximeter

F. Electrocardiography monitor

G. Automatic blood pressure device or manual blood pressure monitoring device

H. Gloves, mask, eye protection

I. Laryngoscope handle and blade(s): usually sizes #3 and #4 curved, #2 and #3 straight

J. Endotracheal tubes: usually 7.0- or 7.5-mm for adult women and 8.0-mm for adult men

K. Malleable stylet

L. Yankauer and tracheal suction catheters, suction device

M. Magill forceps

N. 10-mL syringe to inflate cuff

O. Water-soluble lubricant

P. Qualitative CO_2 detector, CO_2 monitor, or esophageal detector device

Q. Tape or tracheal tube stabilization device

R. Resuscitation cart

III. ROUTE OF INTUBATION

A. Orotracheal intubation via direct laryngoscopy

- This route is generally favored in most circumstances, including when cervical spine injury is suspected.

B. Blind nasotracheal intubation

- The nasotracheal route using a blind approach can only be attempted in a spontaneously breathing patient and may be favored by experienced operators in select patients and situations. This technique has the advantage of allowing continued spontaneous ventilation and generally requires less sedation than direct laryngoscopy. It is more time-consuming than direct laryngoscopy and therefore is less useful in emergent intubation. Endotracheal tubes used for nasotracheal intubation have smaller diameters than those used for orotracheal intubation. Nasotracheal intubation should be avoided if basilar skull fracture is suspected and in the presence of coagulopathy. Nasotracheal intubation is discouraged in infants and small children due to anatomic differences compared with adults.

IV. OROTRACHEAL INTUBATION

A. Preparation

1. Don gloves, mask, and eye protection for universal precautions.
2. Explain the procedure, if patient is conscious.

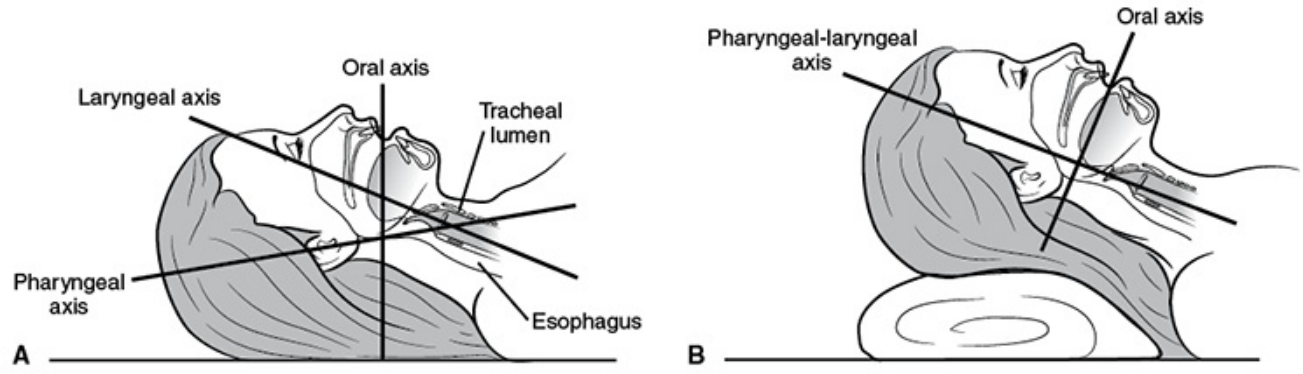
3. Assure patent airway and optimal oxygenation and ventilation (**Chapter 2**).
4. Assure intravenous access.
5. Apply pulse oximeter, electrocardiography, and blood pressure devices.
6. Assemble all equipment and ensure proper working order.
7. Prepare the endotracheal tube.
    a. Check cuff integrity by inflating and fully deflating.
    b. Insert stylet into endotracheal tube, bend to predicted configuration to assist glottic entry. Ensure the distal tip of the stylet does not protrude past the end of the endotracheal tube.
    c. Apply water-soluble lubricant to the cuff end of the tube.
8. Connect laryngoscope blade to handle.
    a. Select blade type (operator's choice).
        1. Straight blade — used to elevate the epiglottis anteriorly
        2. Curved blade — inserted into the vallecula
    b. Select blade length — #3 blade is proper unless patient's neck is very long.
    c. Assure that light is sufficiently bright.
9. Place pad or towel under occiput if cervical spine injury is not suspected.
10. Use topical anesthetic on the patient's oropharynx.
11. Preoxygenate with 100% oxygen for 2 to 3 minutes if time permits.
12. As necessary, proceed with sedation and neuromuscular blockade (**Chapter 2**).

B. Technique

1. The operator stands at the head of the bed, and the bed is raised to a position of comfort for the operator. The head of the bed may be flat or raised slightly per operator preference.
2. When no cervical injury is suspected, a small pad is placed under the occiput (the "sniffing" position) and the neck is gently extended (**Figure A3-1**). When cervical spine injury is possible, these steps are omitted, the neck is stabilized by an assistant (as described in **Chapter 2**), and the anterior portion of the cervical

collar is removed.

Figure A3-1. Positioning for Orotracheal Intubation



The axial planes of the neck are not lined up with the head in a neutral position (**A**). Slight extension and forward movement of the neck will line up the pharyngeal-laryngeal axis and place the oral axis perpendicular to this line, thereby allowing visualization of the vocal cords (**B**). Note that this positioning is contraindicated in patients with possible cervical spine injury.

3. Regardless of the operator's dominant hand in other contexts, the laryngoscope is always held in the left hand.

4. Mouth opening in the sedated/relaxed patient may be assisted by a cross-finger technique wherein the thumb of the right hand is placed on the front lower teeth of the mandible and the first finger on the front upper teeth (maxilla). The mouth is gently opened by a "reverse scissor" movement of the fingers, and the laryngoscope is introduced into the mouth.

5. The tip of laryngoscope blade is inserted into the right side of the patient's mouth (**Figure A3-2**); the blade is advanced to the base of the tongue.

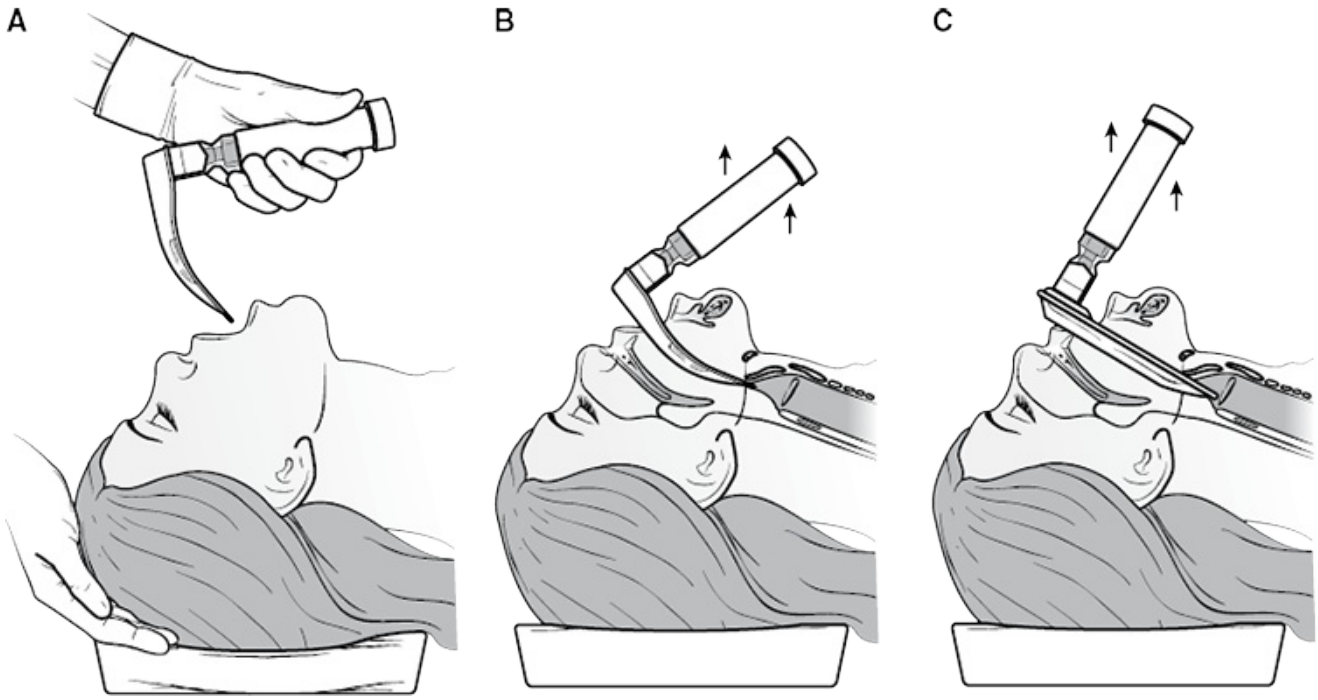
6. The tongue should be swept to the left; proper tongue control is key to laryngeal visualization.

7. The blade is gently advanced further to its proper position. A straight blade is placed beneath the epiglottis; a curved blade is placed into the vallecula above the epiglottis.

8. Caution! Traction should be applied only along the long axis of the laryngoscope handle as the laryngoscope lifts the tongue upward away from the larynx, revealing the glottic opening. A rocking or rotating motion of the blade and handle may damage teeth, gingiva, or lips. The base of the laryngoscope blade should never contact the upper teeth!

9. The vocal cords and glottic opening should be visualized.

Figure A3-2. Insertion of Laryngoscope



(A) The blade of the laryngoscope is inserted into the patient's mouth and pushes the tongue to the left. **(B)** The curved blade follows the base of the tongue and is inserted into the vallecula and **(C)** the straight blade is inserted beneath the epiglottis.

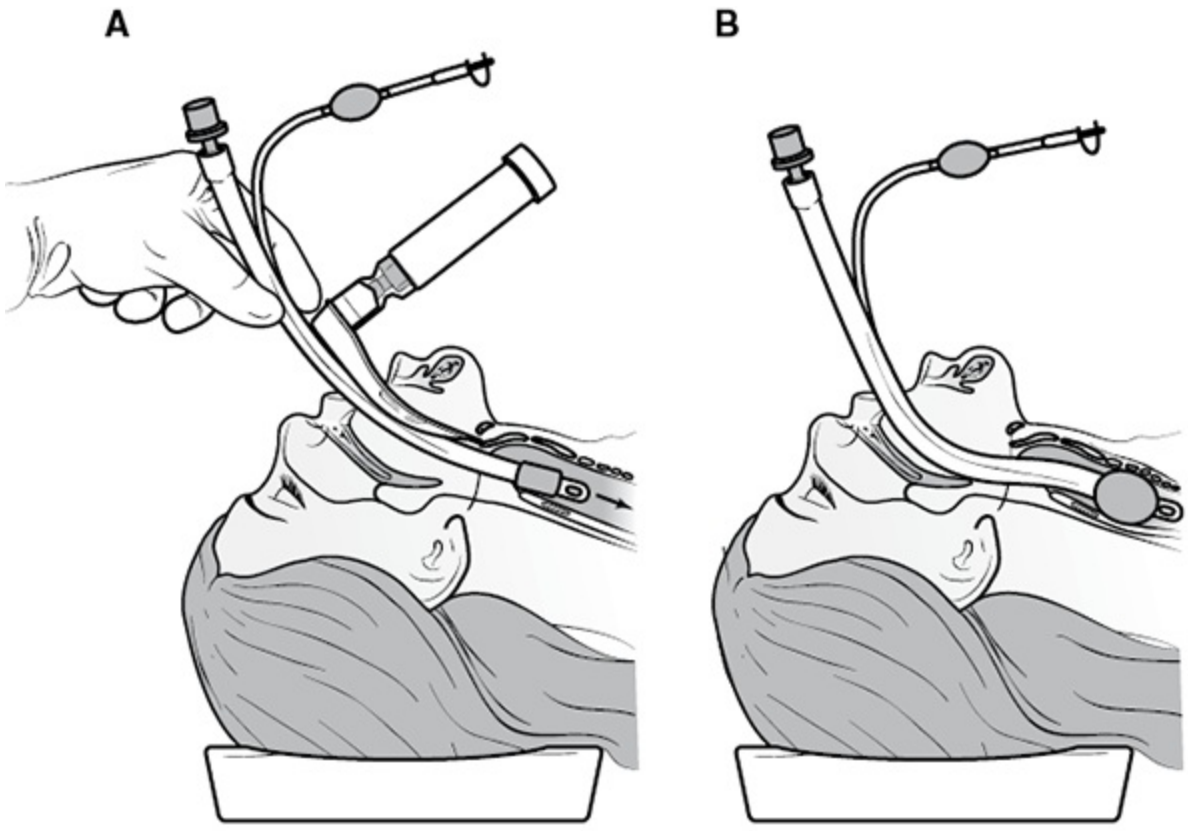
10. If the vocal cords and glottis cannot be visualized, it may be helpful for an assistant to grasp the thyroid cartilage between the thumb and index finger and exert pressure in the following sequence: Pressure is applied backward against the cervical vertebrae and then in an upward direction to shift the larynx superiorly. Additional pressure is applied to shift the thyroid cartilage no more than 2 cm to the right side of the patient's neck. This procedure can be remembered by the acronym BURP (backward, upward, and rightward pressure on the thyroid cartilage).

11. The endotracheal tube is inserted gently through the vocal cords (**Figure A3-3**), holding the tube/stylet with the right hand. The stylet, if angled, may interfere with passage of the tube into the trachea. If resistance is encountered as the tube is advanced, consider having an assistant remove the stylet while the operator holds the endotracheal tube firmly in the glottic opening.

12. The stylet and laryngoscope should be removed carefully (**Figure A3-3**). The operator must continue to hold the endotracheal tube firmly and position it such that the external centimeter length markers on the tube show 21 cm (female) or 23 cm (male) adjacent to the front teeth.

13. The cuff is inflated.

Figure A3-3. Placement of Endotracheal Tube



(A) The endotracheal tube is inserted through the vocal cords until the distal end rests approximately 2 to 3 cm above the carina. **(B)** Once the endotracheal tube is in the proper position, the laryngoscope and stylet are removed and the cuff is inflated.

14. To ensure proper position of the tube:
    a. Auscultate the epigastrium; inspect and auscultate chest to assure equal bilateral gas entry.

    b. Use qualitative CO_2 detector or monitor or esophageal detector device. Lack of color change with a qualitative CO_2 detector or low exhaled CO_2 measurement may occur with a correctly placed tracheal tube in the patient with poor pulmonary perfusion, such as during cardiac arrest or profound hypotension.

    c. Observe for condensation in the endotracheal tube during exhalation.

    d. Listen for breath sounds through the endotracheal tube as the patient is breathing spontaneously.

    e. Obtain chest radiograph (tube tip 2 to 3 cm above carina).

15. Secure endotracheal tube with tape or endotracheal tube stabilization device.

V. BLIND NASOTRACHEAL INTUBATION

A. Preparation

1. See Section IV-A, for preparation for orotracheal intubation, steps 1-6.
2. Position the patient's head on a small towel with the neck in a slightly extended position.
3. Preoxygenate with 100% oxygen for 2 to 3 minutes if time permits.
4. Use topical anesthetic on the nasal passages and pharynx and lubricate the nasal passages.

B. Technique

1. The operator stands at the head of the bed, and the bed is raised to a position of comfort for the operator. The head of the bed may be flat or raised slightly per operator preference. The patient should have spontaneous ventilation and an adequate tidal volume.
2. The larger naris should be used if there is significant deviation of the nasal septum.
3. A well-lubricated endotracheal tube without a stylet is inserted gently through the nasal passage into the posterior oropharynx.
4. Oxygen may be administered by face mask/blowby or by intermittently connecting the oxygen source to the endotracheal tube.
5. The oropharynx should be inspected to assure that the endotracheal tube is in the midline.
6. The amount of air movement at the endotracheal tube connector is assessed by either listening to air movement through the tube, using a specially designed "whistle," or using an exhaled CO_2 monitor.
7. The endotracheal tube is advanced slowly while feeling and listening for air movement at the connector end of the endotracheal tube. Advancement continues if air movement increases through the tube. If air movement decreases, the endotracheal tube should be withdrawn until air movement resumes, re-advancing

after repositioning the head.

8. Advancing the tube through the glottis is usually easier during inspiration.
9. The operator must continue to hold the endotracheal tube firmly and position it such that the external centimeter length markers on the tube show approximately 24 cm (female) or 26 cm (male) adjacent to the naris.
10. The cuff is inflated.
11. To ensure proper position of the tube:
    a. Auscultate epigastrium; inspect and auscultate chest to assure equal bilateral gas entry.
    b. Use qualitative CO_2 detector or monitor or esophageal detector device. Lack of color change with a qualitative CO_2 detector or low exhaled CO_2 measurement may occur with a correctly placed endotracheal tube in the patient with poor pulmonary perfusion.
    c. Observe for condensation in the endotracheal tube during exhalation.
    d. Listen for breath sounds through the endotracheal tube as the patient is breathing spontaneously.
    e. Obtain chest radiograph (tube tip 2 to 3 cm above carina).
12. The endotracheal tube is secured with tape or endotracheal tube stabilization device.

VI. PEDIATRIC CONSIDERATIONS

A. Anatomic differences between adults and children:

1. The larynx is more cephalad in infants than in adults, making it appear more anterior and resulting in a more difficult visualization during laryngoscopy.
2. In young children, the narrowest part of the airway is at the level of the cricoid cartilage, not at the larynx, making an anatomic “cuff” below the vocal cords.
3. In general, the diameter of the small finger approximates the properly sized endotracheal tube. A full-term neonate can accept a tube with a 3.5-mm internal diameter.

4. Cuffed tubes therefore are usually limited to use in children >8 years old (endotracheal tube size >6.0-mm internal diameter); uncuffed tubes are generally used in younger children.

B. Technique differences between adults and children:

1. Head position: a towel roll under the head is often needed in adults to achieve the sniffing position; a shoulder roll is usually needed to achieve this position in infants.
2. Laryngoscope blade selection: operator may choose a straight or curved blade; however, most clinicians do not use curved blades in infants. A common mistake in intubating a child is choosing a blade that is too small. The blade must be long enough to reach the epiglottis.
3. Proper depth of insertion (in centimeters) can be estimated by multiplying the internal diameter of the endotracheal tube by 3 (eg, internal diameter = 4.0; depth of insertion = 4.0 × 3 = 12.0 cm).
4. Appropriately sized equipment (eg, face mask, laryngoscope, endotracheal tube, suction catheter) should be used.

VII. PRECAUTIONS/COMPLICATIONS

A. Hypoxia, hypercapnia during procedure

B. Cardiovascular compromise during and immediately after procedure

C. Damaged teeth, lips, gingiva

D. Malpositioned tube (esophagus, right main-stem bronchus)

E. Pharyngeal, laryngeal, tracheal damage

F. Gastric distension and aspiration of gastric contents

G. Bronchospasm

H. Pneumothorax

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Balk RA. The technique of orotracheal intubation. *J Crit Illness*. 1997;12:316-323.

2. Knill RL. Difficult laryngoscopy made easy with a "BURP." *Can J Anaesth*. 1993;40:279-282.

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INTRAOSSEOUS NEEDLE INSERTION

I. INTRODUCTION

A. Intraosseous (IO) vascular access was first introduced by Drinker in 1922 and first reported in humans in 1934 by Josefson.

B. IO access can be easily achieved by users with little training.

C. IO access is recommended as the immediate alternative when IV access cannot be rapidly achieved.

D. IO access provides a noncollapsible venous plexus for rapid fluid administration.

E. All fluids, blood products, and medications can be given by the IO route.

F. IO access can be used to obtain blood samples for laboratory evaluations.

II. CONTRAINDICATIONS

A. Ipsilateral fracture

B. Compartment syndrome

C. Infection at site of insertion

D. Osteogenesis imperfecta

E. Previous attempts at the same site

F. Previous orthopedic procedures near insertion site

G. Inability to locate landmarks or excessive tissue

III. DEVICES

A. Bone Injection Gun (BIG) [WaisMed Inc., New York, NY], spring-loaded device

B. Arrow EZ-IO Intraosseous Vascular Access System (Teleflex, Morrisville, NC), battery-powered device

C. FAST1 Intraosseous Infusion System (Pyng Medical Corp., Richmond, BC, Canada), to apply in the manubrium

D. Jamshidi Intraosseous Needle (Baxter Healthcare Corp., McGaw Park, IL), manual device

E. Near Needle Holder (Near Manufacturing Ltd., Camrose, AB, Canada), needle holder device

F. Sussmane-Raszynski Intraosseous Infusion Needle (Cook Medical Inc., Bloomington, IN), manual device

IV. EQUIPMENT

A. IO needle or trocar options, depending on the site of insertion and patient age

B. Gloves

C. Antiseptic solution

D. Syringes for infiltration of local anesthetic, blood sampling, and flushes

E. Hypodermic needle

F. Lidocaine 1%

G. Connecting tubing

H. Tape and gauze

V. SITE SELECTION

A. Neonates
    1. Proximal anterior tibia, just below the growth plate, distal to the tibial tuberosity

B. Infants up to 1 year of age
    1. Proximal anterior tibia, 1 cm distal to the tibial tuberosity

C. Children older than 1 year
    1. Proximal anterior tibia, 1 fingerbreadth distal to the tibial tuberosity

D. Adults
    A. Proximal anterior tibia

    B. Proximal metaphysis of the humerus

    C. Sternum

    D. Distal tibia, proximal to the medial malleolus

    E. Distal radius and distal ulna

    F. Distal femur, above the femur plateau

    G. Anterior-superior iliac spine

    H. Calcaneus

VI. TECHNIQUE FOR PROXIMAL TIBIAL INSERTION

A. Apply universal precautions.

B. Palpate the tibial tuberosity and locate the insertion site 2 fingerbreadths distal to the tuberosity.

C. Create a sterile field (if clinical situation permits).

D. Infiltrate a local anesthetic in a conscious patient.

E. Place the patient in the supine position with knee flexed; stabilize the knee with a hand under the popliteal fossa.

F. Insert the needle 90° through the skin until it touches the bone. Apply downward pressure for powered devices, and add clockwise and counterclockwise rotation for manual devices.

G. Advance the needle until the loss of resistance (needle has passed through the bone cortex); the needle should stand freely and upright without support.

H. Remove the trocar and aspirate marrow into the syringe, discarding the first few milliliters of blood (thick fibrin mesh).

I. For needles without a trocar (Near Needle Holder), flush the needle with saline first (needle may be plugged with bone debris).

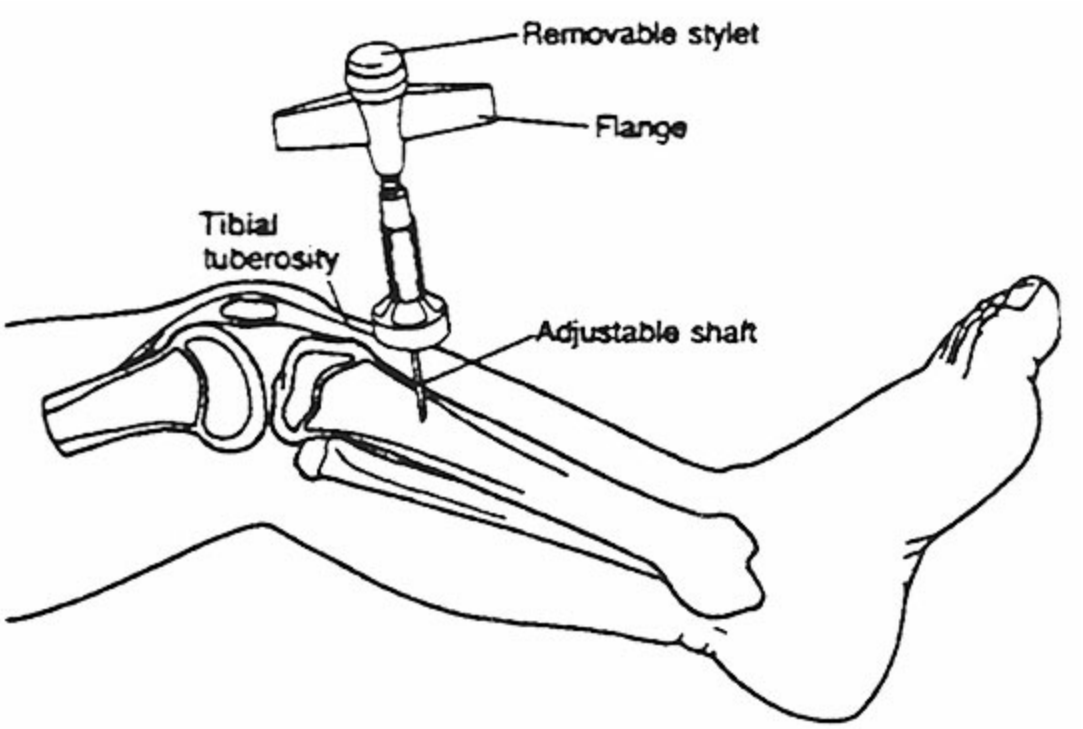
J. Secure the needle by taping flanges to the skin or stabilize with bulky gauze dressing.

K. Draw blood for laboratory analysis.

L. Start infusions, observing the surrounding tissues for possible extravasation.

M. Remember to flush the needle with 5 mL of saline solution after administration of every medication.

Figure A4-1. Intraosseous Needle Insertion[a]



Approach to puncture of the proximal anterior tibia. [a]From: Fiser DH. Intraosseous infusion. *N Engl J Med*. 1990;322(22):1579-1581. Copyright © 1990 Massachusetts Medical Society. Reprinted with permission from Massachusetts Medical Society.

VII. IO REMOVAL

A. Discontinue IO once peripheral or central venous access is established.

B. Stabilize the extremity and withdraw the trocar/needle, maintaining the axial alignment of the needle. Use an upward clockwise and counterclockwise rotation until the needle exits the bone cortex.

C. Apply pressure to the puncture site for approximately 5 minutes.

D. Apply a sterile dressing.

VIII. COMPLICATIONS

A. Inability to place the needle, bending or breaking the needle

B. Subcutaneous extravasation

C. Bone fracture

D. Through-and-through penetration

E. Compartment syndrome

F. Clogged needle

G. Local infection (cellulitis, subcutaneous abscess, osteomyelitis)

H. Pneumothorax, mediastinal hematoma, mediastinitis (in sternal IO access)

I. Pulmonary fat embolus

J. Pain

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

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ARTERIAL BLOOD GAS ANALYSIS AND TREATMENT

These acid-base problems are provided for practice in analyzing arterial blood gas and electrolyte information and determining appropriate interventions.

For complicated acid-base disorders, it may be helpful to understand the utility of the delta gap (Δgap). In an uncomplicated anion gap (AG) metabolic acidosis, every AG increase of 1 mmol/L beyond the normal value should result in a concomitant decrease of approximately 1 mmol/L in [HCO_3]. Deviation from this relationship suggests a mixed acid-base disorder. The difference between the change in the AG and the change in [HCO_3] from the normal values is the Δgap, which can be expressed as:

$$\Delta\text{gap} = (\text{deviation of AG from normal}) - (\text{deviation of } [HCO_3] \text{ from normal})$$

The normal value for Δgap should be 0. However, variance in measurements can result in a Δgap of 0 ± 6. If the Δgap is positive, then a simultaneous metabolic alkalosis exists. If the decrease in [HCO_3] is greater than the increase in AG, which results in a negative Δgap, then a concomitant normal AG acidosis (hyperchloremic) may exist. Small deviations of the Δgap may not indicate mixed acid-base disorders, and clinical information must always be considered.

For purposes of analyzing the following cases, assume that a normal HCO_3 is 24 mmol/L and a normal AG is 12 mmol/L using the formula:

$$[Na] - ([Cl] + [HCO_3])$$

Case 1

A 78-year-old woman with hypertension and hyperlipidemia is admitted to the intermediate care unit for ongoing evaluation and management of a community-acquired pneumonia. She was admitted 12 hours ago from the emergency department. She remains tachypneic with increased work of breathing. Vital signs are: heart rate 105 beats/min, blood pressure 110/68 mm Hg, respiratory rate 22 breaths/min, and temperature 38.4°C (101.2°F). Physical examination reveals bilateral rhonchi and

normal mental status. She is receiving supplemental oxygen at 3 L/min via nasal cannula, and oxygen saturation on pulse oximetry is 88%. An arterial blood gas measurement is made as part of her ongoing workup, with the following results:

pH 7.47

$Paco_2$ 31 mm Hg (4.13 kPa)

Pao_2 55 mm Hg (7.33 kPa)

HCO_3 (calculated) 22 mmol/L

1a. Which one of the following best describes the acid-base disorder?

A. Metabolic acidosis

B. Respiratory alkalosis

C. Respiratory alkalosis and metabolic acidosis

D. Respiratory alkalosis and metabolic alkalosis

1b. Which one of the following is the most appropriate intervention?

A. Intubation and mechanical ventilation

B. Noninvasive ventilation

C. Increase in supplemental oxygen concentration

D. No new intervention

Case 2

A 26-year-old man arrives at the emergency department with multisystem trauma following a motorcycle collision. He is somnolent with a Glasgow Coma Scale score of 13. The primary survey reveals an open airway with equal breath sounds bilaterally. Vital signs are: temperature 36.2°C (97.2°F), heart rate 116 beats/min, respiratory rate 20 breaths/min, blood pressure 100/50 mm Hg, and oxygen saturation on pulse oximetry 99% with a non-rebreather mask in place. The patient undergoes diagnostic radiological evaluations that reveal left rib fractures without hemothorax or pneumothorax. As part of his initial workup, he has blood sent for laboratory analysis. The results are as follows:

pH 7.31

$Paco_2$ 32 mm Hg (4.27 kPa)

Pao_2 163 mm Hg (21.73 kPa)

Na 140 mmol/L

Cl 105 mmol/L

HCO_3 15 mmol/L

2a. Which acid-base disorder is present?

A. Non-anion gap metabolic acidosis

B. Respiratory acidosis

C. Anion gap metabolic acidosis

D. Metabolic acidosis with respiratory alkalosis

2b. What is the suspected cause of the acid-base disorder?

A. Diabetic ketoacidosis

B. Lactic acidosis

C. Uremia

D. Hyperventilation

2c. Which of the following is the most appropriate intervention?

A. Administration of intravenous bicarbonate

B. Fluid and blood product administration

C. No intervention required at this time

D. Intubation

Case 3

A 21-year-old female college student did not wake up the morning after attending a fraternity party where alcohol and drugs were available. Emergency services was called, the patient was placed on supplemental oxygen via non-rebreather mask, peripheral intravenous access was obtained, and fluids were started. Initial vital signs

in the emergency department are: heart rate 102 beats/min, respiratory rate 10 breaths/min, blood pressure 92/60 mm Hg, and oxygen saturation on pulse oximetry 94%. The patient only moans when exposed to noxious stimuli but does localize. Blood is drawn for laboratory evaluation, including an arterial blood gas. The result are as follows:

pH 7.23

$Paco_2$ 60 mm Hg (8.0 kPa)

Na 141 mmol/L

K 4.0 mmol/L

Cl 110 mmol/L

HCO_3 26 mmol/L

3a. Which acid-base disorder is present?

A. Non-anion gap metabolic acidosis

B. Respiratory acidosis

C. Respiratory acidosis and non-anion gap metabolic acidosis

D. Respiratory acidosis and metabolic alkalosis

3b. Which of the following should be the initial intervention?

A. Intubation and intravenous administration of naloxone

B. Administration of activated charcoal

C. Noninvasive positive pressure ventilation

D. No additional intervention

Case 4

A 55-year-old man is admitted to the surgical ICU after elective laparoscopic cholecystectomy. An iatrogenic injury to the hepatic artery required conversion to an open cholecystectomy and fluid resuscitation with normal saline and blood products. Vital signs are: heart rate 115 beats/min, respiratory rate 12 breaths/min (ventilator rate), blood pressure 105/68 mm Hg, and oxygen saturation on pulse oximetry 99% at fraction of inspired oxygen of 50%. Laboratory values are as follows:

pH 7.32

$Paco_2$ 36 mm Hg (4.8 kPa)

Na 146 mmol/L

K 3.8 mmol/L

Cl 117 mmol/L

HCO_3 18 mmol/L

4a. Which acid-base disorder is present?

A. Anion gap metabolic acidosis

B. Anion gap metabolic acidosis and respiratory acidosis

C. Anion gap metabolic acidosis and non-anion gap metabolic acidosis

D. Non-anion gap metabolic acidosis

4b. Which of the following is the most likely cause of the acid-base disorder in this patient?

A. Cardiogenic shock

B. Hemorrhagic shock

C. Normal saline administration

D. Hypoventilation

Case 5

An 81-year-old man was admitted to the medical floor for an exacerbation of congestive heart failure. He received high-dose intravenous furosemide over the last 48 hours, which allowed him to be weaned off noninvasive positive pressure ventilation. He is currently on supplemental oxygen via nasal cannula. Vital signs are: heart rate 88 beats/min, respiratory rate 18 breaths/min, blood pressure 120/72 mm Hg, and oxygen saturation on pulse oximetry 97% on supplemental oxygen at 6 L/min. Laboratory values are as follows:

pH 7.50

$Paco_2$ 45 mm Hg (5.87 kPa)

Na 136 mmol/L
Cl 96 mmol/L
HCO_3 33 mmol/L

5a. Which acid-base disorder is present?

A. Metabolic alkalosis and respiratory acidosis
B. Metabolic alkalosis
C. Metabolic alkalosis and non-anion gap acidosis
D. Respiratory acidosis

5b. Which of the following is the most likely cause of the acid-base disorder?

A. Hypercapnic respiratory failure
B. Volume overload related to congestive heart failure
C. Hypercortisolism
D. Diuretic administration

5c. Which of the following is an appropriate treatment option?

A. Restart noninvasive positive pressure ventilation
B. Administer acetazolamide
C. Continue diuresis with furosemide
D. Decrease administration of furosemide and consider administration of fluids

Case 6

A 58-year-old woman with hypertension and chronic kidney disease is admitted to the hospital with alcohol intoxication. She is somnolent and arouses to painful stimuli. Vital signs are: heart rate 110 beats/min, blood pressure 142/88 mm Hg, respiratory rate 10 breaths/min, temperature 37°C (98.6°F), and oxygen saturation on pulse oximetry 94%. Laboratory results are as follows:

pH 7.23

Na 134 mmol/L

$Paco_2$ 38 mm Hg (5.06 kPa)

K 6.1 mmol/L

PaO2 78 mm Hg (10.4 kPa)

Cl 100 mmol/L

HCO_3 15 mmol/L

Blood urea nitrogen 62 mg/dL

Creatinine 3.7 mg/dL

Glucose 125 mg/dL

6. Which one of the following best describes the acid-base disorder?

A. Anion gap metabolic acidosis

B. Anion gap metabolic acidosis and metabolic alkalosis

C. Anion gap metabolic acidosis and respiratory acidosis

D. Anion gap metabolic acidosis and non-anion gap metabolic acidosis

Case 7

An 80-year-old man with hypertension, diabetes, and malnutrition is admitted to the hospital with cough, fever, and hypotension. Chest radiograph shows a right lower lobe pneumonia. Vital signs are: heart rate 115 beats/min, blood pressure 90/52 mm Hg, respiratory rate 20 breaths/min, temperature 38.3°C (101°F), and oxygen saturation on pulse oximetry 95% on oxygen supplemented at 8 L/min via nasal cannula. Laboratory results are as follows:

pH 7.35

Na 132 mmol/L

$Paco_2$ 32 mm Hg (4.27 kPa)

K 4.0 mmol/L

Pao_2 78 mm Hg (10.4 kPa)

Cl 103 mmol/L

HCO_3 17 mmol/L

Blood urea nitrogen 20 mg/dL

Creatinine 1.4 mg/dL
Albumin 1.5 g/dL

7. Which one of the following best describes the acid-base disorder?

A. Anion gap metabolic acidosis

B. Non-anion gap metabolic acidosis

C. Non-anion gap metabolic acidosis and respiratory alkalosis

D. Anion gap metabolic acidosis and non-anion gap metabolic acidosis

Case 8

A 60-year-old man with arterial vascular disease and hypertension presented to the emergency department with complaints of shortness of breath and abdominal pain. Vital signs are: heart rate 90 beats/min, blood pressure 168/96 mm Hg, respiratory rate 25 breaths/min, temperature 37.2°C (99°F), and oxygen saturation on pulse oximetry 98% while receiving oxygen at 2 L/min via nasal cannula. Laboratory results are as follows:

pH 7.55
Na 135 mmol/L
$Paco_2$ 15 mm Hg (2.0 kPa)
K 3.8 mmol/L
Pao_2 98 mm Hg (13.07 kPa)
Cl 101 mmol/L
HCO_3 13 mmol/L

8a. Which one of the following best describes the acid-base disorder?

A. Acute respiratory alkalosis

B. Chronic respiratory alkalosis

C. Acute respiratory alkalosis and metabolic alkalosis

D. Acute respiratory alkalosis and metabolic acidosis

8b. Which one of the following is a potential etiology of the acid-base disorder?

A. Pulmonary embolism

B. Sepsis

C. Diuretics

D. D. Chronic obstructive lung disease and renal failure

Case 9

A 70-year-old woman is admitted to the ICU with syncope after several days of vomiting. Vital signs are: heart rate 140 beats/min, blood pressure 80/50 mm Hg, respiratory rate 24 breaths/min, and temperature 37.0°C (98.6°F). Laboratory results are as follows:

pH 7.30

Na 138 mmol/L

$Paco_2$ 36 mm Hg (4.8 kPa)

K 3.0 mmol/L

Pao_2 88 mm Hg (11.73 kPa)

Cl 93 mmol/L

HCO_3 20 mmol/L

Glucose 90 mg/dL

9. Which one of the following best describes the acid-base disorder?

A. Anion gap metabolic acidosis

B. Anion gap metabolic acidosis and metabolic alkalosis

C. Anion gap metabolic acidosis and respiratory acidosis

D. Anion gap metabolic acidosis and non-anion gap metabolic acidosis

Case 10

A 55-year-old diabetic, hypertensive man presents with nausea, vomiting, and abdominal pain. Vital signs are: heart rate 124 beats/min, blood pressure 102/50 mm Hg, respiratory rate 22 breaths/min, and temperature 36.4°C (97.6°F). Laboratory results are as follows:

pH 7.45
Na 134 mmol/L
$Paco_2$ 34 mm Hg (4.53 kPa)
K 3.2 mmol/L
Pao_2 85 mm Hg (11.33 kPa)
Cl 85 mmol/L
HCO_3 23 mmol/L
Glucose 420 mg/dL

10. Which one of the following best describes the acid-base disorder?

A. Respiratory acidosis and metabolic acidosis
B. Respiratory acidosis, metabolic acidosis, and metabolic alkalosis
C. Respiratory alkalosis, metabolic acidosis, and metabolic alkalosis
D. Respiratory alkalosis and metabolic acidosis

Case Study Answers and Rationales

Case 1

1a. The correct answer is B, Respiratory alkalosis.

The pH is alkalemic. The low $Paco_2$ suggests a respiratory process rather than a metabolic process. The formula to determine if the respiratory process is acute is:

$$\text{Increase in pH} = 0.08 \times \frac{(40 - Paco_2)}{10}$$

Using the information from the case, the expected increase in pH would be 0.072, resulting in an expected pH 7.47. This finding suggests a pure respiratory process. You can further analyze it by considering whether there is appropriate buffering of HCO_3 using the following formula:

$$\text{Decrease in } [HCO_3] = 2 \times \frac{\Delta Paco_2}{10}$$

Data from the blood gas measurements suggest a decrease of $[HCO_3]$ of 1.8 mmol/L, which is close to the decrease of 2 mmol/L of the calculated $[HCO_3]$.

Although the patient is at risk for a metabolic acidosis, the appropriate decrease of $[HCO_3]$ in relation to the respiratory alkalosis makes that a less likely condition. Clinically, you would always review the electrolytes along with the arterial blood gas and calculate the anion gap. There is no suggestion of a metabolic alkalosis with the near normal $[HCO_3]$.

1b. The correct answer is C, Increase in supplemental oxygen concentration.

The patient is significantly hypoxic but based solely on the information presented, she may not need any more support than an increase in oxygen concentration and continued monitoring. Any worsening of her respiratory rate or mental status may necessitate positive pressure support.

Case 2

2a. The correct answer is C, Anion gap metabolic acidosis.

The pH is acidemic. The low bicarbonate concentration is consistent with a metabolic process. The next step is to determine if appropriate respiratory compensation is present.

Appropriate $Paco_2$ compensation = 1.5 x $[HCO_3]$ + 8 ± 2

In this case, the appropriate compensation would yield $Paco_2$ 30.5 ± 2 mm Hg. Thus, respiratory compensation is appropriate. The next step is to calculate the anion gap.

AG = [Na] – ([Cl] + $[HCO_3]$)

AG for this case = [140] – [(105+15)] = 20 mmol/L

This patient has an elevated anion gap metabolic acidosis. With an anion gap acidosis, the Δgap should be calculated to determine if additional metabolic processes are present.

Δgap = (deviation of AG from normal) – (deviation of $[HCO_3]$ from normal)

= (20-12) – (24-15)

= -1 mmol/L

This is within the normal range of 0 + 6, indicating that no additional metabolic process is present.

2b. The correct answer is B, Lactic acidosis.

The causes of elevated anion gap metabolic acidosis can be remembered with the following mnemonic MUDPILES, which stands for methanol, uremia, diabetic ketoacidosis, paracetamol/acetaminophen, isoniazid, lactic acidosis, ethylene glycol or methanol, and salicylates.

This case depicts a trauma patient in shock with hypoperfusion, resulting in lactic acidosis.

2c. The correct answer is B, Fluid and blood product administration.

The goal is restore perfusion to the tissues. This patient is experiencing hypovolemic hemorrhagic shock. The treatment is fluid and blood product administration and control of the hemorrhage.

Case 3

3a. The correct answer is B, Respiratory acidosis.

The pH is acidemic. The increase in $Paco_2$ indicates a respiratory process. Next, determine if this is an acute or chronic respiratory process.

For an acute respiratory acidosis,

$$\text{the decrease in pH} = 0.08 \times \frac{\Delta Paco_2}{10}$$

Thus, the decrease in pH = 0.08 x 20/10 = 0.16, which is close to the observed value of 60 mm Hg (8.0 kPa). This is an acute respiratory process.

If metabolic compensation is present, the bicarbonate concentration will increase 1 mmol/L for every 10 mm Hg (1.33 kPa) increase in $Paco_2$. For this case, there is a 20 mm Hg change in $Paco_2$ that should translate into a 2 mmol/L increase in bicarbonate. The HCO_3 concentration is 26 mmol/L, which is 2 mmol/L above the normal value of 24 mmol/L and consistent with appropriate metabolic compensation.

3b. The correct answer is A, Intubation and intravenous administration of naloxone

This patient has hypoventilation related to drug and alcohol intoxication. Activated

charcoal will not reverse the respiratory depression. The patient also was not found until the following morning, making it too late for use of activated charcoal. The severely depressed mental status prohibits the use of noninvasive positive pressure ventilation; a patient must be conscious with the ability to protect the airway for noninvasive positive pressure ventilation to be used. This patient should be intubated to control her respiratory failure, and naloxone can be administered simultaneously.

Case 4

4a. The correct answer is D, Non-anion gap metabolic acidosis.

The correct answer is D, Non-anion gap metabolic acidosis.

The pH is academic and the change in HCO_3 concentration would indicate a metabolic process. The next step is to evaluate whether the respiratory compensation is appropriate.

Respiratory compensation: $1.5 \times [HCO_3] + 8 \pm 2$

Respiratory compensation: $1.5 \times [18] + 8 \pm 2 = 35 \pm 2$

In this case the patient has appropriate respiratory compensation. The next step is to determine if the anion gap is elevated.

$$AG = [Na] - ([Cl] + [HCO_3])$$
$$146 - (117 + 18) = 11 \text{ mmol/L}$$

There is no elevation in the anion gap, so this patient has a non-anion gap metabolic acidosis.

4b. The correct answer is C, Normal saline administration.

Metabolic acidosis with a normal anion gap, which is a hyperchloremic acidosis, may result from gastrointestinal or renal loss of HCO_3 or volume resuscitation with normal saline. In this case, the patient received excess fluid resuscitation due to hemorrhage in surgery. This patient has metabolic acidosis as a result of hyperchloremia from normal saline resuscitation.

Cardiogenic shock and hemorrhagic shock would result in metabolic acidosis with an elevated anion gap. Hypoventilation would be associated with a respiratory acidosis. The appropriate intervention is to change to an intravenous fluid with lower chloride content, such as Ringer lactate.

Case 5

5a. The correct answer is B, Metabolic alkalosis.

The pH is alkalemic. The increase in [HCO_3] indicates a metabolic process. Respiratory compensation in metabolic alkalosis is determined by the following formula:

Increase in $Paco_2$ = 0.6-0.7 x Δ[HCO_3] = 0.6-0.7 x 9 = 5.4-6.3 mm Hg (0.72-0.84 kPa)

Thus, the increase in $Paco_2$ is appropriate respiratory compensation. Calculation of the anion gap yields a normal result of 7 mmol/L.

5b. The correct answer is D, Diuretic administration.

Metabolic alkaloses are usually characterized as chloride-depleted (hypovolemic) or chloride-expanded (hypervolemic). In this patient, diuretic use is the most likely cause of the alkalosis.

5c. The correct answer is D, Decrease administration of furosemide and consider administration of fluids.

Chloride-depleted metabolic alkalosis is corrected by administration of an intravenous normal saline infusion. Discontinuation of the furosemide should occur to prevent further depletion of chloride and further exacerbation of metabolic alkalosis. Careful monitoring of the fluid status is indicated in a patient with history of heart failure, and expert consultation is required.

Case 6

6. The correct answer is C, Anion gap metabolic acidosis and respiratory acidosis.

The pH is acidemic and the low [HCO_3] indicates a metabolic process. The formula for determining the expected respiratory compensation is:

$Paco_2$ = 1.5 x [HCO_3] + 8 ± 2

The expected $Paco_2$ would be approximately 30 mm Hg (4.0 kPa). Thus, the finding of a higher $Paco_2$ than expected indicates another acid-base process of respiratory acidosis. The respiratory acidosis is most likely secondary to depressed respiratory drive from intoxication. This patient has ventilatory insufficiency and must be monitored closely for worsening and the potential need for more aggressive ventilatory support. The anion gap

is calculated as an increased value of 19 mmol/L, which is likely secondary to chronic kidney disease, but other unmeasured anions (such as lactate) may be contributing.

The Δgap can be calculated for this case. The deviation of the anion gap from normal is 7 mmol/L, and the deviation of the [$HCO3_3$] from normal is 9 mmol/L. The difference of -2 mmol/L is not likely to represent a third acid-base process.

Case 7

7. The correct answer is A, Anion gap metabolic acidosis.

The pH is acidemic and the low [HCO_3] indicates a metabolic process. The formula for determining the expected respiratory compensation is:

$Paco_2 = 1.5 \times [HCO_3] + 8 \pm 2$

Thus, the expected $Paco_2$ would be approximately 33 mm Hg (4.4 kPa). The anion gap is calculated as 12 mmol/L, which appears normal. However, the albumin concentration must be taken into account. A limitation of the traditional approach to acid-base analysis is the effect of hypoalbuminemia on the anion gap. The expected anion gap decreases by 2.5 to 3 mmol/L for every 1 g/dL. In this patient, an albumin of 1.5 g/dL (assuming a normal albumin of 4 g/dL) would decrease the expected anion gap to 5 to 6 mmol/L. Thus, the calculated anion gap of 12 mmol/L is increased by 6 mmol/L. It is important to recognize the presence of the anion gap metabolic acidosis in assessing the severity of illness of this patient. The clinical scenario is consistent with severe sepsis, and a lactic measurement is indicated.

Case 8

8a. The correct answer is D, Acute respiratory alkalosis and metabolic acidosis.

The pH is alkalemic and the low $Paco_2$ indicates a respiratory process. The next step is to determine if this is an acute or chronic respiratory alkalosis. The formula for acute respiratory alkalosis is:

Increase in $pH = 0.08 \times (40 - Paco_2)/10$

Using the data from this case, the expected increase in pH would be 0.2 or pH 7.6, which is higher than 7.55. The formula for chronic respiratory alkalosis is:

Increase in $pH = 0.03 \times (40 - Paco_2)/10$,

Applying it yields a pH increase of 0.075 or pH 7.475. These calculations suggest that there is likely to be a second acid-base disorder present. Calculation of the anion gap as 21 mmol/L identifies the second process of anion gap metabolic acidosis. The Δgap can be also be calculated for this case. The deviation of the anion gap from normal is 9 mmol/L, and the deviation of the [HCO_3] from normal is 11 mmol/L. The difference of -2 is not likely to represent a third acid-base process.

8b. The correct answer is B, Sepsis.

The acid-base pattern can be helpful in suggesting an etiology of a patient's condition. In this case, respiratory alkalosis with anion gap metabolic acidosis is the typical acid-base disorder of sepsis. Salicylate intoxication would also be associated with this acid-base pattern. Pulmonary embolism would typically result in a respiratory alkalosis, with acidosis being unlikely in a hemodynamically stable patient. Diuretic use would primarily result in metabolic alkalosis rather than acidosis. Chronic obstructive lung disease and renal failure would most likely result in a respiratory acidosis and metabolic acidosis.

Case 9

9. The correct answer is B, Anion gap metabolic acidosis and metabolic alkalosis.

The pH is acidemic and the lower HCO_3 indicates a metabolic process. The formula for determining the expected respiratory compensation is:

$Paco_2 = 1.5 \times [HCO_3] + 8 \pm 2$

Using this, the expected $Paco_2$ would be approximately 38 mm Hg (5.07 kPa), which is close to the $Paco_2$ of 36 mm Hg (4.8 kPa). The anion gap is calculated as 25 mmol/L, which identifies the presence of an anion gap metabolic acidosis. The Δgap should also be calculated for this case. The deviation of the anion gap from normal is 13 mmol/L, and the deviation of the [HCO_3] from normal is 4 mmol/L. The difference of 9 mmol/L suggests the presence of a metabolic alkalosis. The [HCO_3] did not decrease as much as expected for the degree of acidosis. The clinical scenario is also suggestive of volume depletion from vomiting, resulting in the metabolic alkalosis. An anion gap metabolic acidosis (lactic acidosis) was the result of hypotension.

Case 10

10. The correct answer is C, Respiratory alkalosis, metabolic acidosis, and metabolic

alkalosis.

The pH in this very ill patient is nearly normal, which should immediately raise the suspicion for complex acid-base disorders. The history is suggestive of possible diabetic ketoacidosis, so the first calculation could be the anion gap, which is increased at 26 mmol/L. Using the formula for determining the expected respiratory compensation for a metabolic acidosis—$Paco_2 = 1.5 \times [HCO_3] + 8 \pm 2$—the expected $Paco_2$ would be approximately 42 mm Hg (5.60 kPa). Since the patient's $Paco_2$ is lower at 34 mm Hg (4.53 kPa), a respiratory alkalosis is present. The Δgap should definitely be calculated for this case. The deviation of the anion gap from normal is 14 mmol/L, and the deviation of the $[HCO_3]$ from normal is 1 mmol/L. The difference of 13 mmol/L suggests the presence of a metabolic alkalosis. The $[HCO_3]$ did not decrease as much as expected for the degree of acidosis. The clinical scenario is consistent with diabetic ketoacidosis with volume depletion from vomiting and a respiratory alkalosis, possibly secondary to pain.

You could also approach the problem by identifying the pH as alkalemic. The lower $Paco_2$ would prompt assessment of whether it is an acute or chronic respiratory process. Acute is more likely, so the formula for acute respiratory alkalosis would be used: Increase in $pH = 0.08 \times (40 - Paco_2)/10$. Based on the data from this case, the expected increase in pH would be 0.048 or pH 7.45, which is similar to the patient's value. The other acid-base processes would still be identified because the anion gap is always calculated.

BRAIN DEATH AND ORGAN DONATION

I. BRAIN DEATH (DEATH BY NEUROLOGIC CRITERIA)

Brain death is usually a clinical diagnosis based on total and irreversible cessation of all brain function, including that of the brainstem. To diagnose brain death, physicians must verify the presence of unresponsive coma, the absence of brainstem reflexes, and the absence of respiratory drive after a CO_2 challenge. To assure that cessation of brain function is irreversible, physicians must determine the cause of the coma, exclude medical conditions that could mimic coma, and observe the patient for a period of time to exclude the possibility of recovery. Diagnostic criteria and methods in brain death may be established by national, state, or hospital policies and vary among institutions and political jurisdictions. Common requirements are summarized in **Table A6-1**. A physician experienced in brain death certification, hospital policy, and relevant laws should always participate in this process.

Local, regional, and national regulations play a significant role in the organ donation process. Clinicians determining the propriety of organ donation must do this with consideration of applicable standards.

Most hospitals have the capability to perform and interpret an electroencephalogram, nuclear medicine scan, or cerebral angiogram. These may be considered the preferred tests in confirming physical findings consistent with brain death. In some jurisdictions, ancillary tests are utilized when uncertainty exists about the reliability of components of the neurologic examination or when the apnea test cannot be performed.

Special interpretation is required for each of these ancillary tests. In adults, ancillary tests are not needed for the clinical diagnosis of brain death and cannot replace a neurologic examination.

Table A6-1	Clinical Criteria for Brain-Death Certification

Prerequisites (all must be present):

1. Coma, irreversible and cause known
2. Neuroimaging explains coma
3. Central nervous system depressant drug effect absent (if indicated, toxicology screen; if

barbiturates given, serum level <10 µg/mL)
4. No evidence of residual paralytics (electrical stimulation if paralytics used)
5. Absence of severe acid-base, electrolyte, endocrine abnormality
6. Normothermia or mild hypothermia (core temperature >36°C [96.8°F])
7. Systolic blood pressure ≥100 mm Hg
8. No spontaneous respirations

Examination (all must be present):
1. Pupils nonreactive to bright light
2. Corneal reflex absent
3. Oculocephalic reflex absent (tested only if cervical spine integrity ensured)
4. Oculovestibular reflex absent
5. No facial movement to noxious stimuli at supraorbital nerve, temporomandibular joint
6. Gag reflex absent
7. Cough reflex absent to tracheal suctioning
8. Absence of motor response to noxious stimuli in all four limbs (spinally mediated reflexes are permissible)

Apnea test (all must be present):
1. Patient is hemodynamically stable
2. Ventilator adjusted to provide normocarbia (P_{CO_2} 35-45 mm Hg)
3. Patient preoxygenated with 100% F_{IO_2} for >10 minutes to Pa_{O_2} >200 mm Hg
4. Patient well-oxygenated with positive end-expiratory pressure of 5 cm H_2O
5. Oxygen provided via a suction catheter to the level of the carina at 6 L/min or attach T-piece with continuous positive airway pressure at 10 cm H_2O
6. Ventilator disconnected
7. Spontaneous respiration absent
8. Arterial blood gas drawn at 8-10 minutes, patient reconnected to the ventilator
9. P_{CO_2} >60 mm Hg or 20 mm Hg rise from normal baseline value

Ancillary testing (only one needs to be performed) to be ordered only if clinical examination cannot be completed due to patient factors, or if apnea testing inconclusive or aborted:
1. Cerebral angiography
2. Hexamethylpropyleneamine oxime (HMPAO) single-photon emission computed tomography
3. Electroencephalography
4. Transcranial Doppler ultrasonography

Information taken from Wijdicks EFM, Varelas PN, Gronseth GS, Greer DM; American Academy of Neurology.Evidence-based guideline update: determining brain death in adults: Report of the Quality Standards Subcommittee of the American Academy of Neurology. *Neurology*. 2010;74(23):1911-1918.

II. ORGAN DONATION

A. BRAIN DEATH

Organs and tissues obtained from donors who fulfill brain-death criteria can be used in

transplantation. This is facilitated by a local organ procurement organization representative, the procurement transplant coordinator, who can provide information about eligibility criteria for specific organs or tissues. The coordinator can assist in or conduct the process of requesting donation from the family.

Immediate goals for stabilizing the brain-dead organ donor include establishing baseline organ function and stabilizing physiology. In general, a central venous catheter and arterial catheter are required. Cultures are obtained with baseline chemistries to rule out immediate infectious and metabolic complications. Chest radiography, echocardiography, bronchoscopy, and coronary angiography may be indicated. Blood type and crossmatch are performed.

Initial fluid management includes crystalloid administration guided by central venous pressure. Vasoactive drugs are often required to maintain perfusion pressure. **Table A6-2** lists standard physiologic goals for initial resuscitation. Other aspects of donor management are more controversial. Donors frequently suffer from panhypopituitarism secondary to ischemia. Vasopressin levels may be extremely low. Dysfunction of the anterior pituitary also may be seen with hormone administration to counteract the loss of corticotropin and thyroid-stimulating hormone. Thyroid hormone and insulin are sometimes given. Insulin therapy is titrated to a blood glucose level of between 120 and 180 mg/dL.

Table A6-2	Suggested Parameters for Optimal Donor Organ Function Before Procurement

Systolic blood pressure >90 mm Hg
Mean arterial pressure >60 to 65 mm Hg
Central venous pressure 4 to 10 mm Hg
Urine output 100 to 200 mL/h, or 1 to 4 mL/kg/h
Arterial oxygen saturation >95 % or Pa_{O_2} >100 mm Hg (13.3 kPa)
Hematocrit >30%
Temperature 97.7°F to 99.5°F (36.5°C to 37.5°C)
Normal electrolyte levels
Serum glucose 120 to 180 mg/dL (6.6 to 9.9 mmol/L)
Eyelids taped shut/eye drops

B. CARDIAC DEATH

Organs may be procured from donors after cardiac death. Once the decision to remove life-sustaining care has been made, families and appropriate patients may be approached regarding the possibility of organ donation after cardiac death. This process is also facilitated by the local organ procurement organization.

Organ procurement takes place in the operating room, where support is withdrawn and a period of asystole typically ensues. The duration of asystole required is directed by local policy; typically, a 2- to 10-minute asystolic interval (pulselessness, apnea, unresponsiveness) is observed. Up to 10% of potential donors maintain cardiac activity for 60 minutes after discontinuation of life support. Normally, these individuals are not organ donors and receive ongoing end-of-life care.

Two common contingencies may be encountered in donation after cardiac death: unexpected cardiac arrest while awaiting withdrawal of care, and failure to progress to cardiac arrest after withdrawal of support. Management of these episodes is based on patient and family wishes regarding resuscitation and end-of-life care.

Suggested Readings

Current and updated resources for this chapter may be accessed by visiting http://www.sccm.me/fccs6.

1. Shemie SD, Doig C, Dickens B, et al. Severe brain injury to neurological determination of death: Canada forum recommendations. *CMAJ*. 2006;174:S1-13.
2. Shemie SD, Ross H, Pagliarello J, et al. Organ donor management in Canada: recommendations of the Forum on Medical Management to Optimize Donor Organ Potential. *CMAJ*. 2006;174:S13-32.
3. Wijdicks EF. Brain death worldwide: accepted fact but no global consensus in diagnostic criteria. *Neurology*. 2002;58:20-25.
4. Wijdicks EF. The diagnosis of brain death. *N Engl J Med*. 2001;344:1215-1221.
5. Wijdicks EF, Varelas PN, Gronseth GS, Greer DM; American Academy of Neurology. Evidence-based guideline update: determining brain death in adults. Report of the Quality Standards Subcommittee of the American Academy of Neurology. *Neurology*. 2010;74:1911-1918.
6. Wood KE, Becker BN, McCartney JG, D'Alessandro AM, Coursin DB. Care of the potential organ donor. *N Engl J Med*. 2004;351:2730-2739.

Suggested Websites

1. Society of Critical Care Medicine/Guidelines. www.SCCM.org/guidelines.

2. United Network for Organ Sharing. http://www.unos.org.

3. Westphal GA, Caldeira Filho M, Vieira KD, et al. Guidelines for potential multiple organ donors (adult). Part I. Overview and hemodynamic support. *Rev Bras Ter Intensiva*. 2011;23(3):255-268. http://www.scielo.br/pdf/rbti/v23n3/en_v23n3a03.pdf

4. Westphal GA, Caldeira Filho M, Vieira KD, et al Guidelines for potential multiple organ donors (adult). Part II. Mechanical ventilation, endocrine metabolic management, hematological and infectious aspects. *Rev Bras Ter Intensiva*. 2011;23(3):269-282. http://www.scielo.br/pdf/rbti/v23n3/en_v23n3a04.pdf