

edema before a ramp trial is performed. In general, once the patient is ready for weaning, there will be good pulsatility indicating the native cardiac output is perfusing the ascending aorta and great vessels; the blood gas from the right radial artery will reflect the native lung function. It may be desirable to reduce the FiO_2 of the sweep, and reduce the sweep itself to confirm that the patient can oxygenate and ventilate adequately with their own lungs. This will require arterial blood gas analysis. Appropriate anticoagulation is important before the ramp trials; often a small bolus dose of heparin (e.g., 1000 units) is given prior to the trial, and as a general rule bedside ramp trials for VA ECMO in the ICU do not decrease the blood flow below 2 L/min. It is important to keep in mind that other cannulae that may come off the main ECMO circuit will also show a decrease in flow during ramp trials (distal perfusion cannulae or left ventricular vents). Providers should be mindful of this when managing patients with high-risk extremities or threatened limbs (large arterial cannulae and/or technical issues related to the distal perfusion cannula itself). Once it is clear that the ramp trial is successful, patients can then be taken to the operating room for decannulation where they are usually monitored with TEE and a pre-decannulation ramp trial is repeated. In some institutions decannulation can be performed in the bedside in the ICU with an operating room-like setup for surgical repair of the artery.

Weaning from VPA ECMO is similar to weaning from VA ECMO but the focus is on the right heart rather than the left heart, and with at least equal attention to the ability of the patient's own lungs to adequately perform gas exchange.

WEANING FROM VV ECMO

VV ECMO ramp trials are often easier to perform as most of the information regarding the ability of the patient's lungs to oxygenate and ventilate can be learned without a change in circuit flow. The purpose of the VV ECMO circuit is to perform gas exchange, but unlike VA ECMO the pump function provides no cardiac support; weaning trials therefore only need to be performed with changes in gas delivery across the membrane. Decreases in FiO_2 of the sweep to reduce oxygenation support, and decreases in sweep itself across the membrane to reduce "ventilation" (CO_2 removal) are all that is required to assess the adequacy of native lung function. Stopping the flow of oxygen/air across the membrane entirely may be performed as a last step prior to decannulation. This is called a "cap" trial whereby a cap is placed over the gas delivery inlet of the membrane valve itself. However, this process may damage the oxygenator, and if the trial is unsuccessful, may lead to a need to replace it. As a general principle, the sweep should not be reduced below 0.8 L/min for anything but a brief (few minutes) time. Venous ECMO cannulae can usually be removed in the ICU without the need for vascular repair.

WEANING THE PATIENT WITH SEPARATE RVAD, LVAD, AND ECMO

Some patients with biventricular failure and pulmonary edema may have cardiopulmonary support in a configuration of CentriMag LVAD, a CentriMag RVAD, and an oxygenator connected to the RVAD circuit. This cannulation strategy provides separate biventricular support with the

added benefit of an oxygenator in a VV ECMO configuration (i.e., LVAD plus VPA ECMO). It provides the ability to separately assess native lung function, right heart function, and left heart function during ramp trials. The VV ECMO weaning trial can then be performed as described, without a change in LVAD or RVAD blood flow. Reduction in FiO_2 of the sweep and in the sweep itself are monitored with arterial blood gases, with the ability to remove the oxygenator but remain with biventricular support. The RVAD and LVAD can then be weaned separately as determined by the patient's native right- and left-heart function.

Complications of Extracorporeal Membrane Oxygenation

It should not be surprising that there are many complications associated with all types of ECMO. These complications have been the subject of recent systematic reviews both for VA ECMO and for VV ECMO and are also described in the annual reports from ELSO. There is less experience with VPA and VAV ECMO configurations but many of the same issues exist with these more complex circuits. Complications of vascular cannulation, bleeding, or clotting from excessive or inadequate anticoagulation, neurologic injury (i.e., intracerebral bleed) usually related to coagulation management, and infection all occur with a significant incidence. With VA ECMO the majority of vascular complications are arterial; overall vascular complications with VV ECMO, especially the double-lumen Avalon, are less common. Renal injury occurring prior to initiation of ECMO or during an ECMO run is associated with a worse outcome.⁷⁷

Vaquer and associates⁷⁸ performed a systematic review and meta-analysis, selecting 12 studies from 2000 through 2015, including 1042 patients who underwent VV ECMO for ARDS. The mean hospital mortality in these studies was 38%, with a mean of 7% mortality due to complications. They found 40% of patients experienced medical complications, the most common of which was some kind of bleeding (29%). Intracerebral bleeding occurred in 5%. The 2016 ELSO report suggests a similar incidence of bleeding looking at adult ECMO for all respiratory indications. The ELSO report describes an incidence of 10% cannula infections with Vaquer and associates⁷⁸ finding an incidence of all infections of 17%. The ELSO report does not indicate the mortality attributable to complications, but does give overall mortality of respiratory (VV) ECMO as 38% with 42% hospital mortality.¹⁸

For VA ECMO, the majority of which is femoral, the overall incidence of complications related to the ECMO itself is greater than for VV ECMO. This is illustrated in the 2016 ELSO report, and two recent independent reports—one single center and one meta-analysis. In the ELSO report of all cardiac ECMO in adults, the overall incidence of bleeding is 42% rather than 32% for VV ECMO. Infectious complications are comparable, but renal failure and hyperbilirubinemia are both greater. In a meta-analysis of 1866 patients who received VA ECMO for cardiac arrest or cardiogenic shock between 2005 and 2012, Cheng and associates³⁵ found an incidence of major bleeding complications of 40% as well as a similar incidence of needing re-thoracotomy if central ECMO was used after cardiotomy. The incidence

of significant infection was 30% overall. Most strikingly the incidence of acute kidney injury was 55%, with 46% needing dialysis. They also found an incidence of lower extremity ischemia of 17%, compartment syndrome requiring fasciotomy of 10%, and amputation of 5%. They did not report mortality attributable to the ECMO. In a single-center report by Kaushal and associates,⁷⁹ findings associated with hospital mortality included increasing age, the indication for ECMO being cardiac arrest, prolonged ECMO run, need for pre-ECMO dialysis (but not if initiated during ECMO), and limb ischemia.

PERIPHERAL EXTREMITY ISCHEMIA

As indicated previously, limb ischemia, compartment syndrome requiring fasciotomy, and amputation are significant risks of peripheral cannulation for VA ECMO. Approaches to reducing this complication include careful selection of cannula size, meticulous technique in cannula insertion to prevent vessel injury, and interventions to improve flow to the distal extremity such as placement of a distal perfusion cannula or use of an arterial graft where the cannula resides, rather than the vessel itself. Compartment syndrome can be caused by a mismatch in venous outflow to the arterial inflow, which could potentially be avoided by placing the venous and arterial cannulae in different extremities. Other than use of these measures, attentive monitoring of the cannulated extremity for pulses, edema, pain, tissue tension, and temperature, and early intervention if there are ischemic changes, are essential. As mentioned, some centers use oximetry sensors to compare cannulated and non-cannulated extremities.

Hyperperfusion is a less common complication, usually associated with an arterial graft to either a femoral or axillary artery, which then provides the extremity with excessive perfusion leading to hyperemia, patient discomfort, and potentially, compartment syndrome. Chameogeorgakis and associates⁵⁹ report that hyperperfusion syndrome occurs in 20% of patients when the axillary artery is used (with the cannula residing in an end-to-side graft to the artery), and 20% of these patients will go on to develop compartment syndrome. This is a reason why the axillary artery is not a vessel of first choice for VA ECMO. We have also seen this in a lower extremity in a small female patient who had an arterial graft due to small artery size, where the venous cannula was in the femoral vein on the same side.

A number of reports have addressed the effectiveness of distal perfusion catheters^{80,81} and arterial grafts rather than vessel cannulation^{82,83}; while these approaches reduce ischemic complications they do not eliminate them. Vigilance on the part of the care team and early intervention to change cannulation strategy are essential to prevent loss of the limb.

The Anesthesiologist's Role in Extracorporeal Membrane Oxygenation

In many institutions, all ECMO cannulation, management, and decannulation is led by cardiac or thoracic surgeons.

In others, respiratory ECMO is managed by a medical ICU team, even when the cannulation is performed by a surgeon. ECMO management in the ICU can involve cardiologists in patients needing cardiac support, pulmonary physicians in those needing only respiratory support, and critical care physicians of all backgrounds in all patients on ECMO. A critical care anesthesiologist who is also cardiac trained is an ideal participant in the management of these patients as many aspects of ECMO are related to CPB. In some institutions nonsurgical members of the critical care team may be involved in the cannulation and initiation of ECMO as well as its ongoing management. The concept of an ECMO team has been described by two of the authors of this chapter, suggesting that outcomes of ECMO can be significantly improved with the strong engagement of cardiac anesthesiologists and critical care anesthesiologists.⁸⁴ This may be particularly important in "ECMO to go" where a team from the ECMO center travels to an outside hospital to initiate and then manage ECMO as well as other life-support modalities during transfer. The European experience indicates a stronger role for anesthesiologists in this process than in the United States.⁸⁵ Management of patients needing what is essentially a surgical intervention for urgent cardiorespiratory support is very much part of the practice of cardiothoracic anesthesiology, as is the invaluable intraoperative guidance provided by TEE evaluation and monitoring of not only cardiac function, but placement, advancement, and correct positioning of cannulae.⁸⁶ Similarly, during decannulation from cardiac ECMO, echocardiographic evaluation of the heart is essential during and after support has been removed.

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Cardiopulmonary Resuscitation and Advanced Cardiac Life Support

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KEY POINTS

- Cardiac arrest is a major public health issue worldwide. Despite significant advances in resuscitation science, survival rates remain considerably low. Improvement of patient survival and neurologic outcome relies on the development and implementation of vigorous and evidence-based resuscitation guidelines involving basic life support (BLS), advanced cardiovascular life support, and post–cardiac arrest care.
- In cardiac arrests without hypoxic causes, oxygen content in the lungs at the time of cardiac arrest is usually sufficient for maintaining acceptable arterial oxygen content during the first several minutes of cardiopulmonary resuscitation (CPR). Blood flow rather than arterial oxygen content is the limiting factor for oxygen delivery to coronary, cerebral, and systemic circulation during CPR. Thus rescue breaths are less important than initiating effective chest compressions as soon as possible after sudden cardiac arrest (SCA).
- The mechanism through which chest compressions generate blood flow can be explained by the thoracic or cardiac pump theories. The provision of uninterrupted, high-quality chest compressions after SCA is associated with better survival and neurologic outcomes than delaying chest compressions for airway intervention in both adult and pediatric patients. Circulation, airway, breathing has replaced airway, breathing, circulation.
- A single resuscitative shock should be delivered at the earliest possible opportunity after the recognition of cardiac arrest, followed immediately by the resumption of chest compressions without postshock cardiac rhythm analysis. Outcome studies have failed to demonstrate the benefit of a period of chest compressions before shock or for a series of stacked shocks.
- Vasopressor medications during resuscitation have been de-emphasized in deference to providing uninterrupted, high-quality chest compressions. Standard-dose epinephrine (1 mg every 3–5 minutes) is recommended for patients in cardiac arrest. Vasopressin offers no advantage as a substitute for epinephrine in cardiac arrest and has been removed from the adult cardiac arrest algorithm. Steroids combined with a vasopressor bundle or cocktail of epinephrine and vasopressin improved return of spontaneous circulation (ROSC) compared with the use of placebo and epinephrine alone in out-of-hospital cardiac arrest.
- Continuous-flow left ventricular assist devices result in an unconventional, unique physiologic state of hemodynamically stable pulseless electric activity. Assessment of adequate tissue perfusion is the most important factor in determining the need for circulatory assistance such as chest compressions. Total artificial hearts (TAHs) are refractory to chest compressions, antiarrhythmic drugs, and electric therapy. Vasopressor medications are contraindicated because they increase afterload, result in complete hemodynamic collapse with pulmonary edema, and worsen TAH function.
- In consideration of opioid overdose epidemiology, patients with known or suspected opioid addiction who are in cardiac or respiratory arrest should receive intravenous, intramuscular, or intranasal naloxone in addition to standard BLS care.
- For nonshockable rhythms, the essential step will be early detection and correction of potentially reversible underlying causes. Ultrasound technology is used to assess the etiology and the management of these patients, as well as to predict the possibility of ROSC and to justify the termination of resuscitative efforts. However, utilization of this technique should not interfere with other resuscitation efforts such as chest compressions.
- Asphyxiation is a much more common cause of cardiac arrest in infants and children than the primary cardiac event, and airway management and ventilation are therefore more important during the resuscitation of children. However, in order to facilitate training, retention, and implementation of resuscitation guidelines, the pediatric resuscitation guidelines follow similar principles as adult guidelines.

- Targeted temperature management (TTM) applied to comatose survivors of out-of-hospital cardiac arrests has significantly improved the neurologic recovery in those surviving to hospital discharge. A target temperature between 32°C and 36°C is recommended for at least 24 hours, and normothermia (to treat fever) should be maintained beyond this window. Prognostication should not occur until 72 hours after ROSC or, if TTM is provided, 72 hours after completion of TTM.
- Most deaths after SCA in both adults and children typically occur within the first 24 hours. Coordinated postresuscitation care involving access to coronary catheterization capabilities and intensive care management that includes TTM represents the best chance survivors of SCA have for optimal neurologic and cardiac recovery.
- New technologies such as individualized CPR, extracorporeal CPR, controlled automated reperfusion of the whole body (CARL), and emergency preservation for delayed resuscitation may offer opportunities for patients suffering from cardiac arrest.

Sudden Cardiac Arrest and Cardiopulmonary Resuscitation

BRIEF HISTORY AND PHYSIOLOGIC CONSIDERATIONS

Cardiac arrest is a major public health issue, with more than 500,000 deaths per year in the United States.¹⁻³ Seventy percent of out-of-hospital cardiac arrests (OHCA) occur at home, and approximately 50% are unwitnessed. Despite significant advances in resuscitation science, survival rates remain considerably low for both OHCA and in-hospital cardiac arrest (IHCA). Only 10.4% of adult patients with nontraumatic cardiac arrest who receive resuscitative efforts from emergency medical services (EMS) survive to hospital discharge.⁴ IHCA has a better outcome, with 22.3% to 25.5% of adults surviving to hospital discharge.⁵ Statistics for Europe are similar, with OHCA as one of the leading causes of death in Europe and an overall survival rate of 2.6% to 10.7%.⁶⁻⁸

Sudden cardiac arrest (SCA) is a complex and dynamic process. Forward systemic arterial blood flow continues after cardiac arrest until the pressure gradient between the aorta and right heart reaches equilibrium. A similar process occurs with forward pulmonary blood flow between the pulmonary artery and the left atrium. As the arteriovenous pressure gradient diminishes, the left heart filling is decreased, right heart filling is increased, and the venous capacitance vessels become increasingly distended. When the arterial and venous pressures reach equilibration (approximately 5 minutes after no-flow cardiac arrest), coronary perfusion and cerebral blood flows stop. The goal of cardiopulmonary resuscitation (CPR) thus is to maintain oxygen and blood supply to vital organs, restore spontaneous circulation, minimize postresuscitation organ injury, and ultimately improve the patient's survival and neurologic outcome.

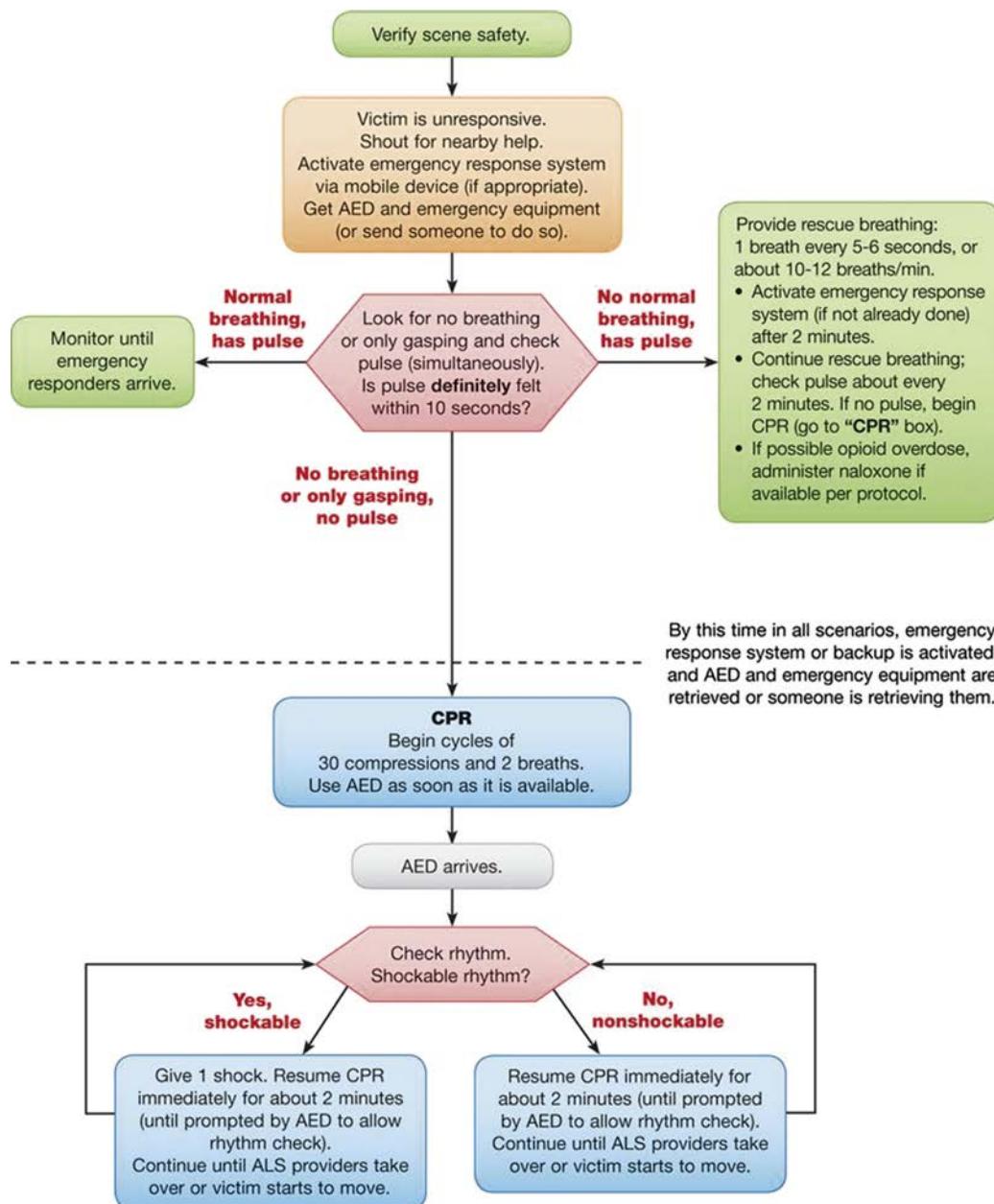
The history of CPR traces back to the biblical age. However, the more contemporary approach to CPR dates back to the 1950s.⁹ James Elam and Peter Safar showed that the earlier methods of resuscitation with chest-pressure and arm-lift were ineffective, and that mouth-to-mouth ventilation was an easily learned and life-saving approach. William B. Kouwenhoven of Johns Hopkins University is credited with introducing a formalized system of chest compressions. Claude Beck of Case Western Reserve University and Paul Zoll of Beth Israel Hospital introduced defibrillation to break ventricular fibrillation.

In 1966 the National Academy of Sciences National Research Council conference generated consensus standards for the performance of CPR and opened the modern era of CPR.

The mechanism through which chest compressions generate blood flow can be explained by the thoracic or cardiac pump theories. The thoracic pump theory postulates that blood flows from the thorax when the intrathoracic vascular pressures exceed extrathoracic pressures.¹⁰ The venous-to-arterial blood flow direction is a result of venous valves that prevent retrograde flow at the thoracic inlet. According to the cardiac pump theory, blood flow is generated as a result of actual compression of the heart between the sternum and the vertebral column.^{11,12} Transesophageal echocardiography (TEE) during CPR in humans allowed direct visualization of changes in cardiac chambers and valve functions during chest compressions, as well as the direction of blood flow. During chest compression, the tricuspid and mitral valves close, the left and right ventricular volumes decrease, and blood is ejected into the arterial system.^{13,14} During the decompression phase of CPR, the pressure gradient between the systemic venous system and thoracic cavity facilitates blood flow into the heart chambers. Systemic blood flow during CPR is dependent on effective chest compressions but also on the venous blood return to the heart. Therefore, even modest increases in the intrathoracic pressure, as might occur with overzealous ventilation during CPR, will impair venous return and negatively impact systemic, coronary, and cerebral perfusions and also reduce the chances of return of spontaneous circulation (ROSC).

Cardiac output during CPR with effective, uninterrupted chest compression is at best 25% to 30% of the normal spontaneous circulation. In cardiac arrests without hypoxic causes (e.g., suffocation, drowning), oxygen content in the lungs at the time of cardiac arrest is usually sufficient for maintaining acceptable arterial oxygen content during the first several minutes of CPR. Blood flow rather than arterial oxygen content is the limiting factor for oxygen delivery to coronary, cerebral, and systemic circulation during CPR. Thus rescue breaths are less important than initiating effective chest compressions as soon as possible after SCA.

Understanding the pathophysiology during SCA and CPR is vitally important. The actual improvement of patient outcome, however, relies on development and implementation of vigorous and evidence-based resuscitation guidelines. The more recent recommendations, the 2015 American Heart Association Guidelines for Cardiopulmonary Resuscitation



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Fig. 86.1 Basic Life Support Healthcare Provider Adult Cardiac Arrest Algorithm—2015 Update. AED, Automated external defibrillator; CPR, cardiopulmonary resuscitation. (From Kleinman ME, Brennan EE, Goldberger ZD, et al. Part 5: Adult Basic Life Support and Cardiopulmonary Resuscitation Quality: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S414–S435.)

and Emergency Cardiovascular Care (2015 American Heart Association [AHA] Guidelines for CPR and ECC), represent the fourth internationally recognized resuscitation guidelines from the AHA and the European Resuscitation Council; therefore, these guidelines are practiced in many countries and medical specialties. More recently, the guidelines underwent a major updating process change. Instead of updating guidelines every 5 years, the new process involves a continuous evidence evaluation process and annual guidelines update, with the most recent one being the 2017 AHA Guidelines for CPR and ECC update. The intent of this chapter is to review the history, rationale, and current understanding of both basic life support (BLS) and advanced cardiovascular life support (ACLS) techniques based on the most recent updated guidelines.

BASIC LIFE SUPPORT

BLS is, according to the Carnegie Safety Institute, the foundation for saving lives after cardiac arrest. Fundamental aspects of adult BLS include immediate recognition of SCA and activation of the emergency response system, early CPR, and rapid defibrillation with an automated external defibrillator (AED). Initial recognition and response to heart attack and stroke are also considered as parts of the BLS. All BLS interventions are time sensitive for preventing SCA, terminating SCA, or supporting circulation until spontaneous circulation is restored. The steps of the adult BLS algorithm for healthcare providers are illustrated in **Fig. 86.1**.

TABLE 86.1 Summary of Components of High-Quality Cardiopulmonary Resuscitation

Component	Adults and Adolescents	Children (Age 1 Year to Puberty)	Infants (Age Less Than 1 Year, Excluding Newborns)
Scene safety	Make sure the environment is safe for rescuers and victim		
Recognition of cardiac arrest	Check for responsiveness No breathing or only gasping (i.e., no normal breathing) No definite pulse felt within 10 s (Breathing and pulse check can be performed simultaneously in less than 10 s)		
Activation of emergency response system	If you are alone with no mobile phone, leave the victim to activate the emergency response system and get the AED before beginning CPR Otherwise, send someone and begin CPR immediately; use the AED as soon as it is available	<i>Witnessed collapse</i> Follow steps for adults and adolescents on the left <i>Unwitnessed collapse</i> Give 2 min of CPR Leave the victim to activate the emergency response system and get the AED Return to the child or infant and resume CPR; use the AED as soon as it is available	
Compression-ventilation ratio without advanced airway	1 or 2 rescuers 30:2	1 rescuer 30:2 2 or more rescuers 15:2	
Compression-ventilation ratio with advanced airway	Continuous compressions at a rate of 100-120/min Give 1 breath every 6 s (10 breaths/min)		
Compression rate	100-120/min		
Compression depth	At least 2 inches (5 cm)*	At least one-third AP diameter of chest About 2 inches (5 cm)	At least one-third AP diameter of chest About 1 1/2 inches (4 cm)
Hand placement	2 hands on the lower half of the breastbone (sternum)	2 hands or 1 hand (optional for very small child) on the lower half of the breastbone (sternum)	1 rescuer 2 fingers in the center of the chest, just below the nipple line 2 or more rescuers 2 thumb-encircling hands in the center of the chest, just below the nipple line
Chest recoil	Allow full recoil of chest after each compression; do not lean on the chest after each compression		
Minimizing interruptions	Limit interruptions in chest compressions to less than 10 s		

*Compression depth should be no more than 2.4 inches (6 cm).

AED, Automated external defibrillator; AP, anteroposterior; CPR, cardiopulmonary resuscitation.

From Kleinman ME, Brennan EE, Goldberger ZD, et al. Part 5: Adult Basic Life Support and Cardiopulmonary Resuscitation Quality: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S414-S435. <https://ecc-guidelines.heart.org/index.php/circulation/cpr-ecc-guidelines-2/part-5-adult-basic-life-support-and-cardiopulmonary-resuscitation-quality/>.

The 2015 AHA Guidelines for CPR and ECC on BLS continue to emphasize the simplified universal adult BLS algorithm. The recommended sequence for a single rescuer is to initiate chest compressions before giving rescue breaths (circulation, airway, breathing [C-A-B] rather than airway, breathing, circulation [A-B-C]) to reduce any delay in providing effective chest compressions in adults without any known information of possible asphyxiation as the cause of cardiac arrest. The single rescuer should begin CPR with 30 chest compressions followed by 2 breaths. The guideline, in addition, also emphasizes a simultaneous, choreographed approach to the performance of chest compressions, airway management, rescue breathing, rhythm detection, and shocks (if indicated) by an integrated team of highly trained rescuers in applicable settings such as the hospital environment. With the current rhythm analysis technology, pause of chest compressions may still be required for accurate rhythm analysis, but the compressions should be resumed as soon as possible after

rhythm analysis or defibrillation. The key components of high-quality CPR for BLS providers are summarized in Table 86.1.

Recognition of Sudden Cardiac Arrest

The necessary first step in the management of cardiac arrest is its immediate recognition. Studies have shown that both lay rescuers and healthcare providers have difficulty detecting a weak pulse.¹⁵ The healthcare provider should take no more than 10 seconds to check for a pulse and, if the rescuer does not definitely feel a pulse within that time period, start chest compressions. Ideally, the pulse check is performed simultaneously with the examination for breathing or gasping, to minimize delay in the detection of cardiac arrest and initiation of CPR. Cardiac arrest victims sometimes present with seizure-like activity or agonal gasps that can confuse potential rescuers. If the victim is unresponsive with absent or abnormal breathing, the rescuer should assume that the victim is in cardiac arrest.

Bystander Cardiopulmonary Resuscitation

For victims of OHCA, the key determinants of survival are timely performance of high-quality bystander CPR and, in the presence of any of the shockable rhythms of ventricular fibrillation or pulseless ventricular tachycardia (VT), defibrillation. Similarly, for IHCA, the important provider-dependent determinants of survival are early defibrillation for shockable rhythms and high-quality CPR, along with recognition and response to deteriorating patients before an arrest. The implication of timely CPR is discussed in the next section of this chapter. The components of high-quality CPR include compressing the chest at an adequate rate and depth, allowing complete chest recoil after each compression, minimizing interruptions in compressions, and avoiding excessive ventilation.

As previously described, chest compressions create blood flow by increasing the intrathoracic pressure and directly compressing the heart. The 2015 AHA Guidelines for CPR and ECC recommended a chest compression rate of 100 to 120/min (updated from at least 100/min), and a chest compression depth for adults of at least 2 inches (5 cm) but not greater than 2.4 inches (6 cm). Despite the “push hard and push fast” recommendation, most CPR feedback devices have shown that compressions are more often too shallow than too deep.¹⁶ In clinical practice, the compression depth may be difficult to judge without the use of feedback devices, and identification of upper limits of compression depth may be challenging. The addition of an upper limit of compression rate is based on a large registry study analysis associating extremely rapid compression rates (greater than 140/min) with inadequate compression depth.¹⁷ Overzealous and rapid chest compressions also compromise chest recoil and venous return, and can potentially have adverse effects on patient survival and outcome.

The total number of compressions delivered during resuscitation is an important determinant of ROSC and survival with good neurologic function from cardiac arrest.^{18,19} The number of compressions delivered is affected by the compression rate (the frequency of chest compressions per minute) and by the compression fraction (the portion of total CPR time during which compressions are performed). Obviously, increases in compression rate and fraction increase the total number of compressions delivered. Compression fraction is improved by reducing the number and duration of any interruptions in compressions (such as securing the airway, delivering rescue breaths, or allowing AED analysis).

Compression-only CPR is easy for an untrained rescuer to perform and can be more effectively guided by dispatchers over the telephone. Moreover, survival rates from adult cardiac arrests of cardiac etiology are similar with either compression only CPR or CPR with both compressions and rescue breaths when provided before EMS arrival.^{20,21} However, for the trained lay rescuer who is able, the recommendation remains for the rescuer to perform both compressions and breaths, especially for victims with asphyxiation causes of cardiac arrest or prolonged CPR. The same emphasis on rescue breathing should also apply to the pediatric population. All lay rescuers should, at a minimum, provide chest

compressions for victims of cardiac arrest. The rescuer should continue CPR until an AED arrives and is ready for use, EMS providers take over care of the victim, or the victim starts to move.

The 2015 AHA Guidelines for CPR and ECC emphasize the initiation of chest compressions before ventilation (i.e., a change in the sequence from A-B-C to C-A-B). The prioritization of circulation (C) over ventilation reflected the overriding importance of blood flow generation for successful resuscitation and practical delays inherent to initiation of rescue breaths (B). Physiologically, in most cases of SCA, the need for assisted ventilation is a lower priority because of the availability of adequate arterial oxygen content at the time of a SCA. The presence of this oxygen and its renewal through gasping and chest compressions (provided there is a patent airway) also supported the use of compression-only CPR and the use of passive oxygen delivery.

Shock First or Chest Compressions?

Previous guidelines recommended a period of chest compressions before attempting defibrillation in unwitnessed cardiac arrests or when CPR had been delayed longer than 4 minutes. However, two recent randomized control trials failed to demonstrate a benefit (ROSC or hospital discharge) when CPR was performed before defibrillation.^{22,23} Thus the 2015 AHA Guidelines for CPR and ECC recommend that for adult witnessed cardiac arrests when an AED is immediately available, the defibrillator should be used as soon as possible. For adults with unmonitored cardiac arrest or for whom an AED is not immediately available, it is reasonable that chest compressions be initiated while the defibrillator equipment is being retrieved and applied, and that defibrillation, if indicated, be attempted as soon as the device is ready for use.

Automated External Defibrillators and Manual Defibrillation

Ventricular fibrillation (VF) and pulseless VT are the most common cardiac arrhythmias encountered during witnessed cardiac arrest in adults. CPR prolongs tissue viability and the duration of VF by providing oxygen and energy substrate, but cannot convert the arrhythmia to an organized rhythm in most circumstances. Defibrillation delivers an electrical current passing through the myocardium to interrupt disorganized cardiac activity and restore an organized cardiac rhythm.²⁴

The first AED was introduced in 1979.²⁵ When it is applied to an individual with possible SCA, the AED analyzes the cardiac rhythm, and then automatically attempts defibrillation if it is VF or rapid VT. A trained rescuer needs to simply apply the defibrillator pads to the patient's chest, activate the AED, and deliver the shock through the push of a button when prompted to do so by the AED. Thus the purpose is to have early defibrillation more readily available through trained bystanders, such as security guards, police, and the general public.

When a standard manual defibrillator is used in resuscitation, the rescuer needs to interpret the rhythm and shock when appropriate. If a monophasic defibrillator is available,

then a single 360 joule (J) shock should be delivered. With biphasic defibrillators, a much lower energy level (150–200 J) is usually sufficient to terminate the arrhythmia due to its ability to compensate and adjust for the patient's impedance. If the rescuer is unfamiliar with the waveform used or the manufacturer recommendations, then the maximal available energy should be used as the default energy. There is no evidence indicating superiority of one biphasic waveform design or energy level for the termination of VF with the first shock. For subsequent shocks, it is reasonable to select fixed versus escalating energy based on the specific manufacturer's instructions.

The same protocol used with the AED should be applied when using the manual defibrillator: (1) emphasis is placed on delivering uninterrupted chest compressions while defibrillator pads are being applied and for periods when rhythm analysis is not occurring; (2) chest compressions are immediately resumed after shock delivery; (3) cardiac rhythm is reanalyzed as indicated after 2 minutes of chest compressions and rescue breathing; and (4) defibrillation is attempted only for VF and rapid VT.²⁶

Single versus Stacked Defibrillation

The 2015 AHA Guidelines for CPR and ECC recommended a 2-minute period of chest compressions after each shock instead of immediate successive shocks for persistent VF.²⁷ The rationale for this is that when VF is terminated, a brief period of asystole or pulseless electrical activity (PEA) typically ensues and a perfusing rhythm is unlikely to be present immediately, necessitating chest compressions to provide organ perfusion and circulation of ACLS drugs. No difference in the 1-year survival or frequency of VF recurrence was shown when a single shock protocol with 2 minutes of CPR between successive shocks was compared against a previous resuscitation protocol employing three initial stacked shocks with 1 minute of CPR between subsequent shocks.^{28,29} A recent study demonstrated that in monitored in-hospital VF/VT arrests, expeditious defibrillation with use of stacked shocks is associated with a higher rate of ROSC and survival to hospital discharge.³⁰ Without further data, current AHA guidelines recommend that a single-shock strategy (as opposed to stacked shocks) is reasonable for defibrillation. Stacked defibrillation is considered only during cardiac surgery or in the cardiac catheterization laboratory where invasive monitoring and defibrillation pads are in place already.

Determination of Efficiency of Cardiopulmonary Resuscitation

Immediately after cardiac arrest, when minute ventilation is constant and carbon dioxide (CO₂) production is unchanged, the changes in the partial pressure of end-tidal CO₂ (PETCO₂) can serve as a reliable surrogate for pulmonary blood flow and cardiac output. This has been proven extensively by animal and human studies during cardiac arrest and CPR and after ROSC.^{31–33} Monitoring of both PETCO₂ by quantitative waveform capnography with controlled ventilation and systemic arterial pressure by invasive monitoring should provide optimal assessment of the efficiency of CPR. These parameters can be monitored continuously, without interrupting chest compressions. An abrupt increase in any of these parameters is a sensitive

indicator of ROSC. The 2015 AHA Guidelines for CPR and ECC endorse this monitoring as a class I recommendation for adults with SCA with an endotracheal tube (ETT) or supraglottic airway (SGA) device in place. In addition, coronary perfusion pressure, arterial relaxation pressure, and central venous oxygen saturation can assist in determination of the efficiency of CPR, although these monitoring techniques require more complex catheters or devices.^{34,35} Currently there are no clinical trials that have studied whether titrating resuscitative efforts to a single or combined set of physiologic parameters during CPR results in improved survival or neurologic outcome. However, the 2010 AHA Guidelines for CPR and ECC recommended that PETCO₂ should be maintained above 10 mm Hg,³⁶ and mathematical models suggest a cumulative maximum PETCO₂ above 20 mm Hg at all time points measured between 5 and 10 minutes postintubation best predicted ROSC.³⁷

Update to Airway Management and Ventilation in Cardiac Arrest

When cardiac arrest occurs, adequate oxygen delivery is required to restore the energy state of the heart as well as other vital organs, and consequently ventilation becomes an essential part of the resuscitation. However, it also needs to be emphasized that during the first few minutes after cardiac arrest, oxygen delivery to tissues with CPR is limited more by blood flow and low cardiac output than arterial oxygen content.³⁸ Low cardiac output associated with CPR results in low oxygen uptake from the lungs that, in turn, reduces the need to ventilate the patient during this low-flow state.³⁸ Thus chest compressions are the priority intervention, unless the cardiac arrest is due to asphyxiation, drowning, or suffocation, which are the only circumstances in which ventilation must be provided before chest compressions.³⁹

Healthcare providers must determine the best way to support ventilation and oxygenation. Options include standard bag-mask ventilation versus placement of an advanced airway (i.e., ETT or SGA device). Bag-mask ventilation with a head tilt–chin lift or head tilt–jaw thrust maneuver is recommended for initial airway control in most circumstances. There is inadequate evidence to show a difference in survival or favorable neurologic outcome with the use of bag-mask ventilation compared with endotracheal intubation or other advanced airway devices.^{40,41} There is also inadequate evidence favoring the use of endotracheal intubation compared with other advanced airway devices.⁴² Thus 2015 AHA/Guidelines for CPR and ECC recommend that either a bag-mask device or an advanced airway may be used for oxygenation and ventilation during CPR in both the in-hospital and out-of-hospital settings, assuming that providers have ongoing experience to insert the airway and verify proper position with minimal interruption in chest compressions. The choice of bag-mask device versus advanced airway insertion is determined by the skill and experience of the provider.

Regarding the inspired oxygen concentration, the 2015 AHA Guidelines for CPR and ECC support providing the maximal inspired oxygen concentration during CPR. Since oxygen delivery is dependent on both blood flow and arterial oxygen content and blood flow is typically limited during CPR, it is theoretically important to maximize the

oxygen content of arterial blood by maximizing inspired oxygen concentration. Evidence for the detrimental effects of hyperoxia that may exist in the immediate post–cardiac arrest period should not be extrapolated to the low-flow state of CPR, where oxygen delivery is unlikely to exceed demand or cause an increase in tissue PO₂. Therefore, until further data are available, physiology and expert consensus support providing the maximal inspired oxygen concentration during CPR.

After ETT placement, it is very important to confirm its correct placement, although this could be very challenging due to the patient's body habitus, low-flow status, and distraction from other resuscitative tasks. In addition to observation of chest rise and auscultation of the lungs and stomach, continuous waveform capnography is recommended as the most reliable method of confirming and monitoring correct placement of an ETT.⁴³ However, false-positive results (CO₂ detection with esophageal intubation) can still occur, especially within the first few breaths due to air/CO₂ insufflation of the stomach during bag-mask ventilation. False-negative results (i.e., absent exhaled CO₂ in the presence of tracheal intubation) can occur in the setting of pulmonary embolism (PE), low cardiac output, or severe obstructive pulmonary disease. If continuous waveform capnography is not available, a nonwaveform CO₂ detector, fiberoptic scope, esophageal detector, or ultrasound device used by an experienced operator are reasonable alternatives.

If bag-mask ventilation is chosen, 2 breaths are delivered after 30 chest compressions during one- and two-person CPR, providing that the rescuer(s) is(are) trained in CPR. Each breath is delivered over approximately 1 second. After placement of an advanced airway, it is recommended to provide 1 breath every 6 seconds (10 breaths/min) while continuous chest compressions are being performed. Extreme caution should be taken to avoid excessive airway pressure that will compromise venous return in cardiac arrest patients, as hyperventilation is common during enthusiastic resuscitation.

ADVANCED CARDIAC LIFE SUPPORT: MANAGEMENT OF CARDIAC ARREST

BLS, ACLS, and post–cardiac arrest care are integral steps in the AHA's "chain of survival" for patients suffering from cardiac arrest. CPR almost invariably necessitates rapid progression to ACLS interventions and follow-up care. There is overlap between these steps, as each stage of care progresses to the next, but generally ACLS comprises the level of care between BLS and post–cardiac arrest care. The 2015 AHA Guidelines for CPR and ECC adult cardiac arrest algorithm is illustrated in Fig. 86.2. This section reviews the different interventions for managing cardiac arrest patients based on the presenting ECG rhythm, medications used during cardiac arrest, special situations of cardiac arrest, and new technologies developed to facilitate resuscitation and improve the patient's survival.

Asystole

Asystole is the complete and sustained absence of electrical activity and portends extremely poor prognosis. Management of a patient in cardiac arrest with asystole follows the

same pathway as management of PEA (as discussed later). The top priorities are also similar: following the steps in the ACLS Pulseless Arrest Algorithm and identifying and correcting any treatable, underlying causes for the asystole. In most patients, asystole is irreversible, but a brief trial of resuscitation, beginning with effective chest compressions, oxygen therapy, and intravenous (IV) epinephrine, is indicated particularly in the setting of witnessed cardiac arrest. Atropine is no longer recommended for treating asystole. Asystole should be differentiated from agonal bradycardia and fine ventricular fibrillation.

Pulseless Electrical Activity

PEA refers to the presence of organized electrical activity without a palpable pulse. Priority must be given to identifying possible reversible causes of PEA, which is frequently referred to as the five Hs (Hypoxia, Hypovolemia, Hypothermia, Hyper- or Hypokalemia, Hydrogen ions or acidosis) and Ts (Tamponade, Tension pneumothorax, Toxins, Thrombosis Pulmonary, and Thrombosis Coronary). Those causes are first suspected for each patient's special circumstance. Severe hypoxia in respiratory emergencies can result in PEA. In the traumatized patient, hypovolemia, cardiac tamponade, and tension pneumothorax are possible causes of cardiac arrest and must be considered and acutely treated. Unanticipated cardiac arrest occurring in the intraoperative and postoperative periods should include acute massive pulmonary thromboembolism or air emboli as possible causes. Electrolyte and metabolic derangements such as severe hyperkalemia, metabolic acidosis, or drug (e.g., digitalis, β -blockers, calcium channel blockers, tricyclic antidepressants) overdose frequently presents as idioventricular rhythms. In every circumstance, prompt initiation of chest compressions and the administration of 1 mg epinephrine are recommended as temporizing measures until more definitive therapy can be provided once the cause for the PEA is identified. Each of these scenarios has an associated intervention unique to that situation. Asystole or VF can develop if PEA is not corrected.

Pulseless Ventricular Tachycardia or Ventricular Fibrillation

Pulseless VT and VF are shockable rhythms and hence the most treatable causes of cardiac arrest, yielding the greatest likelihood of ROSC and long-term survival in both in-hospital and out-of-hospital settings. Early defibrillation, not pharmacologic intervention, is responsible for the improved survival after VF cardiac arrest. Therefore, AEDs are placed in public locations to ensure early defibrillation can be performed by rescuers.

When a pulseless VT or VF arrest occurs, defibrillation should be performed at the earliest opportunity. Chest compressions should be immediately resumed after the delivery of shock and continued for 2 minutes before reassessing the underlying cardiac rhythm, unless obvious evidence for ROSC occurs. No evidence supports one biphasic waveform over another. Defibrillation energies should be increased until VF is terminated. In circumstances in which pulseless VT or VF is terminated with defibrillation but pulseless VT or VF recurs, defibrillation should use the previously successful energy level.

If ROSC does not occur after an initial defibrillatory attempt, then five cycles of CPR consisting of 30

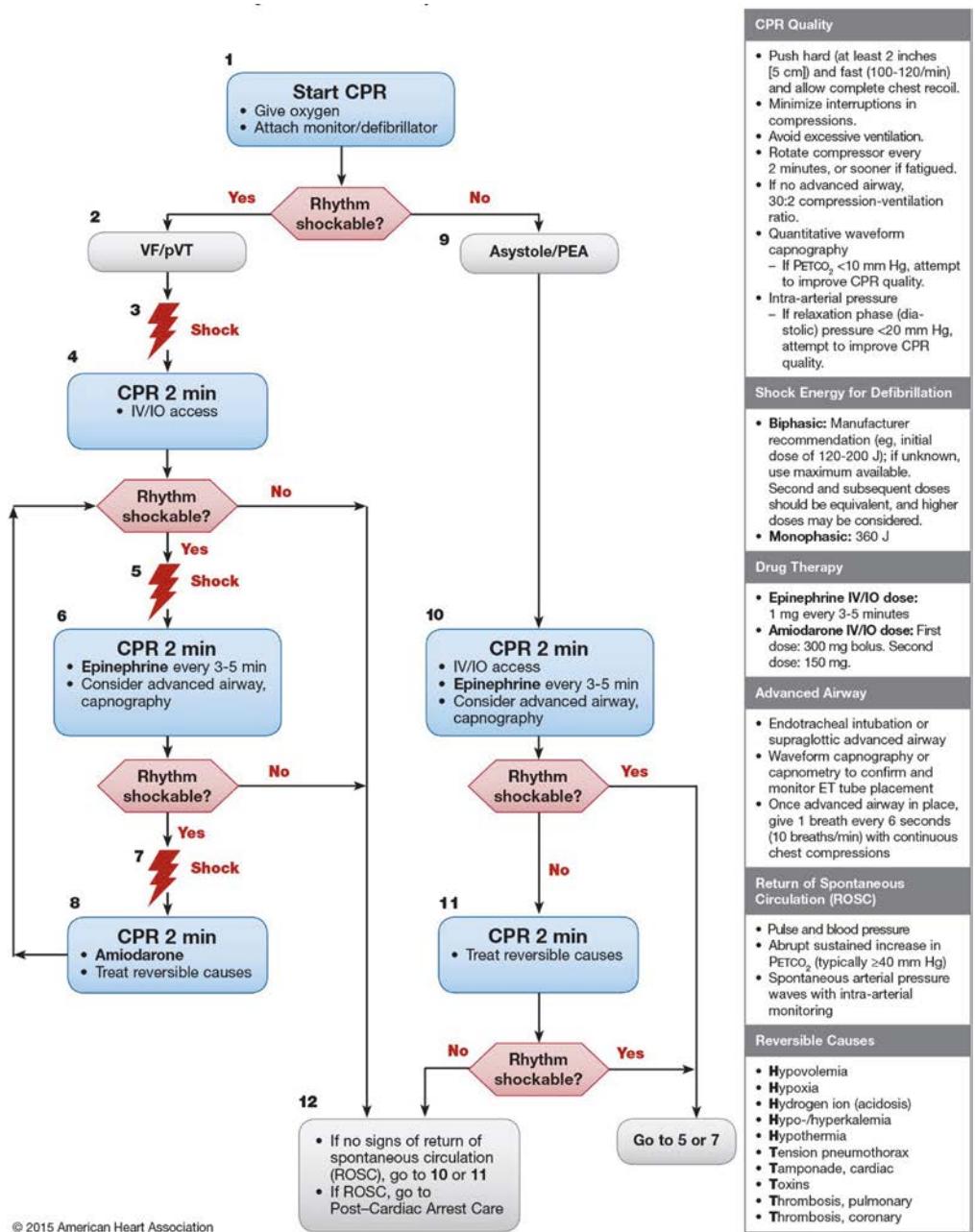


Fig. 86.2 2015 American Heart Association adult advanced cardiovascular life support algorithm. *CPR*, Cardiopulmonary resuscitation; *IO*, intraosseous; *IV*, intravenous; *PEA*, pulseless electric activity; *VF*, ventricular fibrillation; *VT*, ventricular tachycardia. (From Link MS, Berkow LC, Kudenchuk PJ, et al. Part 7: Adult Advanced Cardiovascular Life Support: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S444-S464.)

compressions to 2 ventilations (nonintubated patient) should be performed before recheck of rhythm. Placement of a SGA device or endotracheal intubation can be considered in this interval. Peripheral IV access should be attempted if not already established without interruption of the chest compressions.

Resuscitation Medications During Cardiac Arrest

Epinephrine. Epinephrine produces beneficial effects in patients during cardiac arrest, primarily due to its α -adrenergic effects increasing coronary perfusion pressure and cerebral perfusion pressure during CPR. The β -adrenergic effects of epinephrine are controversial

because they may increase myocardial work and reduce subendocardial perfusion. Thus standard-dose epinephrine (1 mg every 3-5 minutes) is recommended for patients in cardiac arrest. High-dose epinephrine is not recommended for routine use in cardiac arrest. The exceptions to this recommendation are special circumstances requiring higher or repeated doses of epinephrine, such as in patients with β -blocker overdose, calcium channel blocker overdose, or when epinephrine is titrated to real-time physiologically monitored parameters.

Regarding the timing of epinephrine administration, multiple trials showed the early administration of epinephrine in nonshockable rhythms (asystole or PEA) was associated

with increased ROSC, survival to hospital discharge, and neurologically intact survival.^{44,45} For shockable rhythms (VF or pulseless VT), there is insufficient evidence to make a recommendation as to the optimal timing of epinephrine, particularly in relation to defibrillation. Therefore early administration of epinephrine is recommended after the onset of cardiac arrest caused by an initial nonshockable rhythm.

Vasopressin. Vasopressin is a nonadrenergic peripheral vasoconstrictor that also causes coronary and renal vasoconstriction. Studies compared multiple doses of standard-dose epinephrine with multiple doses of vasopressin (40 units IV) or vasopressin in combination with epinephrine after OHCA and showed no benefit with the use of vasopressin solely or in combination with epinephrine for ROSC or survival to discharge with or without good neurologic outcome.⁴⁶ Vasopressin offers no advantage as a substitute for epinephrine in cardiac arrest and thus has been removed from the adult cardiac arrest algorithm.

Antiarrhythmia Medications. The role of antiarrhythmic medications during shock-refractory VF/pulseless VT is to facilitate the restoration and maintenance of a spontaneous perfusing rhythm in concert with the shock termination of VF, instead of directly converting VF/pulseless VT to an organized perfusing rhythm. Some antiarrhythmic drugs have been associated with increased rates of ROSC and hospital admission, but none have yet been proven to increase long-term survival or survival with good neurologic outcome. Thus the 2015 AHA Guidelines for CPR and ECC on ACLS recommend that amiodarone may be considered for VF/pulseless VT that is unresponsive to CPR, defibrillation, and a vasopressor therapy; and lidocaine may be considered as an alternative to amiodarone. Routine use of magnesium for VF/pulseless VT is not recommended in adult patients, nor is the routine use of sodium bicarbonate for any patient in cardiac arrest.

Steroids. The use of steroids in cardiac arrest has been assessed in both IHCA and OHCA settings. In IHCA, patients administered steroids combined with a vasopressor bundle or cocktail of epinephrine and vasopressin had improved ROSC compared with patients given a saline placebo and epinephrine.⁴⁷ However, further studies are needed before recommending the routine use of this therapeutic strategy. For patients with OHCA, studies showed inconsistent benefit of use of steroids alone during CPR and thus routine use is not recommended.

Cardiopulmonary Resuscitation in Patients With Mechanical Circulatory Support

Cardiac arrest in patients on mechanical circulatory support (MCS) has become a much more common clinical scenario due to the increased use of this therapy in patients with end-stage heart failure. Because of the unique characteristics of mechanical support, these patients have physical findings that cannot be interpreted the same as for patients without MCS. This section briefly describes the common types of MCS devices that healthcare providers may encounter and presents expert, consensus-based recommendations from the recent AHA guidelines for the evaluation and resuscitation of adult patients with MCS, and suspected cardiovascular collapse or cardiac arrest.⁴⁸

MCS with ventricular assist devices (VADs) can support function of the left ventricle (LV), the right ventricle (RV), or both ventricles with a biventricular assist device. A total artificial heart (TAH) replaces the heart itself. Most patients who are discharged home with MCS currently have a durable left ventricular VAD (LVAD). Continuous-flow LVADs are the more current generation of VADs. It results in an unconventional, unique physiologic state of hemodynamically stable PEA, which we refer to in this population as pseudo-PEA. Vital signs such as noninvasive blood pressure or oxygen saturation may be difficult to obtain. These factors can easily confuse healthcare providers rendering care to these patients. Lack of a pulse alone in a patient with a continuous-flow LVAD is common and cannot be used as a means to determine whether a patient is in cardiac arrest or a low-flow, low-perfusion state.

Assessment of adequate tissue perfusion is the most important factor in determining the need for circulatory assistance such as chest compressions. Clinical findings such as skin color and capillary refill are reasonable predictors of the presence of adequate flow and perfusion. If an LVAD is definitively confirmed by a trained person and there are no signs of life, bystander CPR, including chest compressions, is recommended. Many tachyarrhythmias are tolerated well in patients with an LVAD, although they can affect RV filling. Similar to the decision made for patients without VADs, the decision to cardiovert or to defibrillate a patient with an LVAD with VT or VF is based on the adequacy of mental status and perfusion. Fig. 86.3 outlines consensus-derived recommendations for first-responder assessment of a patient with an LVAD.

For patients with a TAH, the native ventricles are removed completely; therefore, there is no electric depolarization and therefore no detectable ECG tracing. Chest compressions are ineffective because the mechanical ventricles are rigid and cannot be compressed. Antiarrhythmic drugs and electric therapy (e.g., pacing, defibrillation/cardioversion) are also futile for similar reasons. Standard vasopressor drugs used in ACLS such as epinephrine or vasopressin are contraindicated because they increase afterload, result in complete hemodynamic collapse with pulmonary edema, and worsen TAH function. The only therapeutic option is to try to restore mechanical function of the device. One liter of normal saline solution should be administered intravenously to treat for possible hypovolemia. Assisted ventilation should be performed as needed, and the patient should be transported to the hospital as soon as possible. Fig. 86.4 provides an algorithm for evaluation and treatment of a patient with a TAH who is altered mentally, unresponsive, or in respiratory distress.

Cardiopulmonary Resuscitation Using a Mechanical Cardiopulmonary Resuscitation Device

Delivering high-quality chest compressions to achieve ROSC and maintain perfusion to vital organs is vitally important to improving survival and neurologic outcome after cardiac arrest. However, manual conventional chest compressions are frequently affected by fatigue, varying skill levels and training, pauses during defibrillation and the switch of rescuers, and adherence to protocols.⁴⁹ It is even more difficult to ensure high-quality chest compressions

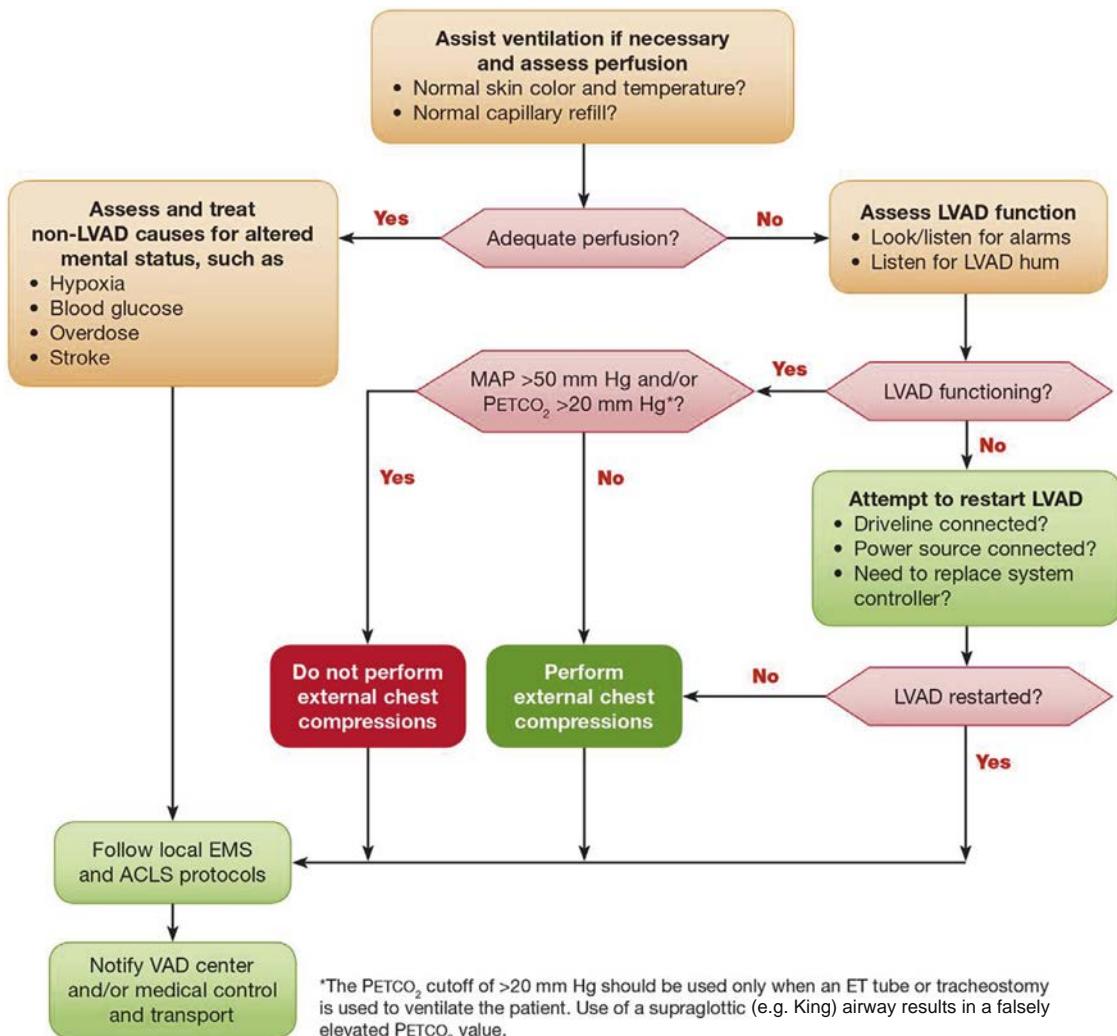


Fig. 86.3 Algorithm showing response to a patient with a left ventricular assist device (LVAD) with unresponsiveness or other altered mental status. ACLS, Advanced cardiovascular life support; EMS, emergency medical services; ET, endotracheal tube; MAP, mean arterial pressure; PETCO₂, partial pressure of end-tidal carbon dioxide; VAD, ventricular assist device. (From Peberdy MA, Gluck JA, Ornato JP, et al. Cardiopulmonary Resuscitation in Adults and Children With Mechanical Circulatory Support: A Scientific Statement From the American Heart Association. *Circulation*. 2017;135[24]:e1115–e1134.)

during transport.⁵⁰ Studies showed that manual compressions provide only approximately 30% of normal cardiac output, at best.⁵¹ Mechanical chest compression devices have therefore been developed to improve CPR. These devices are designed to deliver compressions of consistent rate and depth, eliminate fatigue as a factor, and provide an opportunity to reduce the frequency and length of pauses in compression.

Initial experimental studies with the mechanical chest compression device showed improved organ perfusion pressures, enhanced cerebral blood flow, and higher end-tidal CO₂ compared with manual CPR.^{52,53} A recent large multicenter randomized controlled trial showed, nevertheless, that an algorithm combining mechanical chest compressions and defibrillation during ongoing compressions provided no survival advantage over manual CPR administered according to guidelines.⁵⁴ No difference in survival or neurologic outcome was seen for up to 6 months after the cardiac arrest, even though the mechanical chest compression devices reduced interruptions in chest compressions, and enabled defibrillation during ongoing compressions.

The possible explanation for this discrepancy between early studies and the large clinical trial is that application of the mechanical device resulted in long pauses of chest compression (median device application time 36.0 seconds), and pause in chest compression is clearly associated with worse clinical outcome. Therefore the 2015 AHA Guidelines for CPR and ECC recommended that manual chest compressions remain the standard of care for the treatment of cardiac arrest, but mechanical CPR devices may be a reasonable alternative for use by properly trained personnel in specific settings where the delivery of high-quality manual compressions may be challenging or dangerous for the provider (e.g., limited rescuers available, prolonged CPR, during hypothermic cardiac arrest, during preparation for extracorporeal CPR [ECPR]). Future emphasis should be placed on streamlining and appropriately timing the deployment of these compression devices.

Echocardiography in Cardiac Arrest

For nonshockable rhythms, the essential step will be early detection and correction of potentially reversible underlying

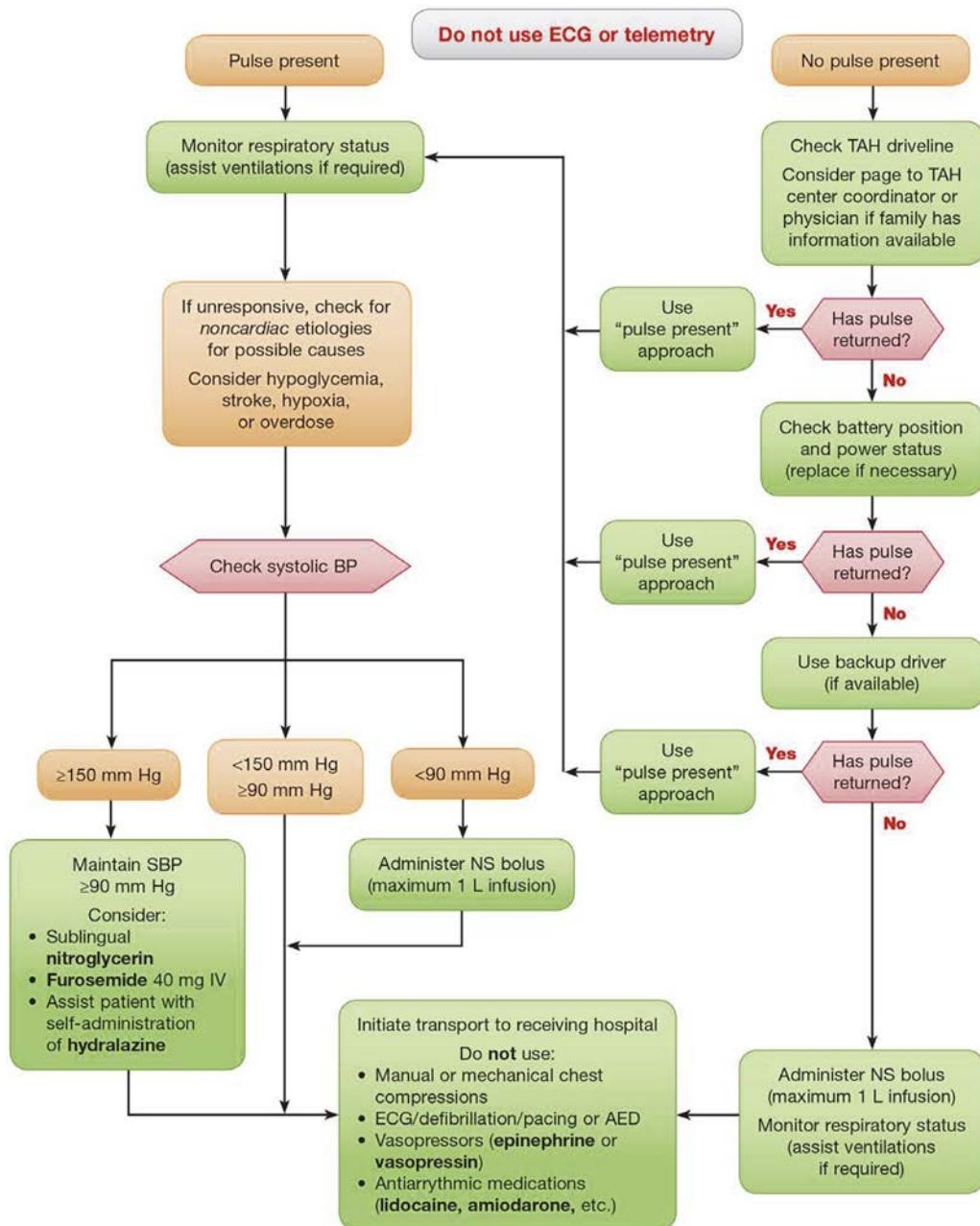


Fig. 86.4 Algorithm showing response to a patient with a total artificial heart (TAH) with altered mental status, unresponsiveness, or respiratory distress. AED, Automated external defibrillator; BP, blood pressure; IV, intravenous; NS, normal saline; SBP, systolic blood pressure. (From Peberdy MA, Gluck JA, Ornato JP, et al. Cardiopulmonary Resuscitation in Adults and Children With Mechanical Circulatory Support: A Scientific Statement From the American Heart Association. *Circulation*. 2017;135(24):e1115–e1134.)

causes, such as the Hs and Ts of PEA arrest, as described earlier. Echocardiography has revolutionized our ability to assess the etiology and hence the management of these patients. However, performing and interpreting echocardiography frequently proves much more challenging in the real scene of cardiac arrest.

Point-of-care (POC) focused echocardiography can help assess the volume status, ventricular function, valvular disease, cardiac tamponade, PE, and tension pneumothorax. The TEE, compared with transthoracic echocardiography, provides constant visualization of the heart during chest compressions and gives live feedback on cardiac contractility and the quality of compressions.

It is less affected by the body habitus, presence of subcutaneous air, and by chest movements. Several studies have evaluated the feasibility and clinical influence of TEE in cardiac arrest patients. TEE showed moderate sensitivity and specificity for diagnosing cause of arrest, and may further impact treatment.^{55,56} However, it is unclear if these benefits will be translated to improved patient outcome. Thus the 2015 AHA Guidelines for CPR and ECC suggested that if a qualified sonographer is present and use of ultrasound does not interfere with the standard cardiac arrest treatment protocol, then ultrasound may be considered as an adjunct to standard patient evaluation and resuscitation measures.

More recently, POC focused echocardiography has also been used to predict short-term outcome in patients with cardiac arrest. Recent meta-analysis showed spontaneous cardiac movement had a sensitivity of 95% and specificity of 80% to predict ROSC, and sensitivity 90% and specificity 78% to predict survival to hospital admission.⁵⁷ Absence of spontaneous cardiac movement on echocardiography has a low likelihood of favorable outcome and can aid in the decision of termination of resuscitation. The caveat is that the interpretation of spontaneous cardiac movement is still very operator-dependent. In addition, in cases of significant bradycardia, the image could be potentially interpreted as cardiac standstill between the cardiac contractions.

Cardiac or Respiratory Arrest Associated With Opioid Overdose

In the United States in 2013, 16,235 people died of prescription opioid toxicity, and an additional 8257 died of heroin overdose.⁵⁸ In 2012, opioid overdose became the leading cause of unintentional injurious death in people aged 25 to 60 years in the United States, accounting for more deaths than motor vehicle collisions.⁵⁹ A majority of these deaths are associated with prescription opioids. In consideration of this epidemiology, the 2015 AHA Guidelines for CPR and ECC on BLS recommended that for patients with known or suspected opioid addiction who are unresponsive with no normal breathing but a pulse, it is reasonable for appropriately trained lay rescuers and BLS providers, in addition to providing standard BLS care, to administer intramuscular (IM) or intranasal naloxone.

The ideal dose of naloxone is unknown. In the 2010 AHA Guidelines for CPR and ECC, an empiric starting dose of 0.04 to 0.4 mg IV or IM was recommended to avoid provoking severe opioid withdrawal in patients with opioid dependency and to allow for consideration of a range of doses, depending on the clinical scenario. Repeat doses or dose escalation to 2 mg IV or IM was recommended if the initial response was inadequate. Regardless of the care setting and route of administration, the initial goal of therapy is to restore and maintain patent airway and ventilation, preventing respiratory and cardiac arrest, without provoking severe opioid withdrawal.

Recognition and Emergency Response for Suspected Stroke

Each year, about 6.5 million people die from stroke worldwide, and 1 million from cerebrovascular diseases in the 15 countries of the European Union.^{60,61} According to the 2013 Global Burden of Disease study, stroke is the second largest contributor to disability-adjusted life years (113 million disability-adjusted life years) in the world after ischemic heart disease, is a major cause of disability, and is the second most common cause of dementia, after Alzheimer disease. Identifying clinical signs of possible stroke (sudden weakness or numbness of the face, arm, or leg, especially on one side of the body; sudden confusion, trouble speaking, or understanding; sudden trouble seeing in one or both eyes; sudden trouble walking, dizziness, loss of balance, or coordination; or sudden severe headache with no known cause) is important because fibrinolytic treatment must be provided within a few hours of onset of symptoms.^{62,63} Community and professional education is essential to increase the early recognition and treatment to improve patient outcome.

The AHA and American Society of Anesthesiologists developed a community-oriented “stroke chain of survival” that links actions to be taken by patients, family members, and healthcare providers to maximize stroke recovery. Important components of this chain are rapid recognition and reaction to stroke warning signs, rapid EMS dispatch, transport and hospital pre-notification, and rapid diagnosis and treatment in the hospital. The algorithm goals for management of patients with suspected stroke is illustrated in Fig. 86.5.

Recognition and Management of Specific Arrhythmias

This section highlights recommendations for management of patients with acute symptomatic arrhythmias. It needs to be emphasized that electrocardiographic and rhythm information should be interpreted within the context of total patient assessment. For example, when a patient with respiratory failure and severe hypoxemia becomes hypotensive and develops a bradycardia, the bradycardia is not the primary cause of instability. Treating the bradycardia without treating the hypoxemia is unlikely to improve the patient’s condition. Errors in diagnosis and treatment are likely to occur if ACLS providers base their treatment decisions solely on rhythm interpretation and neglect the clinical evaluation of each specific patient.

In general, “unstable arrhythmias” refer to a condition in which vital organ function is acutely impaired due to inefficient cardiac contractions and insufficient cardiac output, or cardiac arrest is ongoing or imminent. When an arrhythmia causes a patient to be unstable, immediate intervention is indicated. “Symptomatic arrhythmias” imply that an arrhythmia is causing symptoms, such as palpitations, lightheadedness, or dyspnea, but the patient is stable and not in imminent danger. In such cases, more time is available to decide on the most appropriate intervention. In both unstable and symptomatic cases, the provider must make an assessment as to whether the arrhythmia is causing the patient to be unstable or symptomatic. It is critically important to determine the cause of the patient’s instability in order to properly direct the treatment.

BRADYARRHYTHMIAS

Bradycardia is defined as a heart rate of less than 60 beats/min. However, when bradycardia is the cause of symptoms, the rate is generally less than 50 beats/min. A slow heart rate may be physiologically normal for some patients, whereas a heart rate of more than 50 beats/min may be inadequate for others. Hence, 50 beats/min is a relative number, and it is important to also assess the patient’s clinical presentation.

Depending on the origin of the arrhythmia, bradyarrhythmias can be classified as supraventricular (sinus, junctional, or various degrees of atrioventricular [AV] block) or ventricular (complete heart block with a very slow idioventricular escape rhythm). Sinus (or junctional) bradycardia and type I (AV nodal) second-degree block are usually manifestations of increased vagal tone. AV blocks are classified as first, second, and third degree. A first-degree AV block is defined

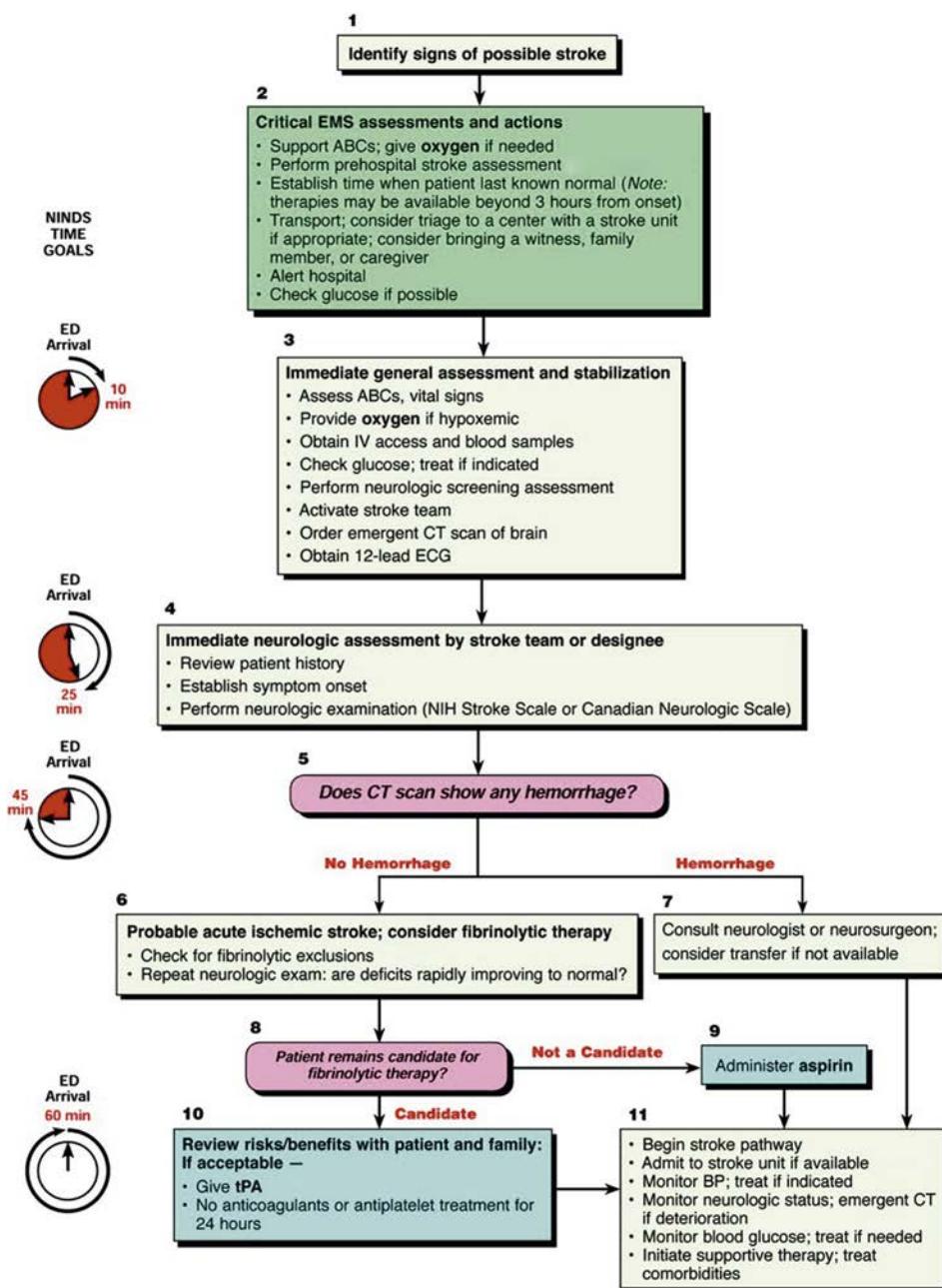


Fig. 86.5 American Heart Association Algorithm for Suspected Stroke. ABC, Airway, breathing, circulation; BP, blood pressure; CT, computed tomography; EMS, emergency medical services; IV, intravenous. (From ECC Committee, Subcommittees and Task Forces of the American Heart Association: Part 9: Adult Stroke: 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2005;112:IV-111-IV-120.)

by a prolonged PR interval (>0.20 second) and is generally benign. Second-degree AV block is divided into Mobitz types I and II. In Mobitz type I block, the block is at the AV node and is often transient and asymptomatic. In Mobitz type II block, the block is usually below the AV node within the His-Purkinje system; this block is often symptomatic, with the potential to progress to complete (third-degree) AV block. Third-degree AV block may occur at the AV node, bundle of His, or bundle branches. When third-degree AV block is present, the atria and ventricles are completely dissociated. Third-degree AV block can be permanent or transient, depending on the underlying cause.

Because hypoxemia is a common cause of bradycardia, initial evaluation of any patient with bradycardia should

focus on signs of increased work of breathing (tachypnea, intercostal retractions, suprasternal retractions, paradoxical abdominal breathing) and oxygen saturation as determined by pulse oximetry. If oxygenation is inadequate or the patient shows signs of increased work of breathing, supplementary oxygen should be provided. A monitor should be attached to the patient for blood pressure, ECG, and oxygen saturation monitoring, and IV access should be established. If possible, obtain a 12-lead ECG to better define the rhythm. While initiating treatment, evaluate the patient's clinical status and identify potentially reversible causes.

The provider must identify signs and symptoms of poor perfusion and determine if those signs are likely to be caused by the bradycardia. If the signs and symptoms are not due

to bradycardia, the provider should reassess the underlying cause of the patient's symptoms. Asymptomatic or minimally symptomatic patients do not necessarily require treatment unless there is suspicion that the rhythm is likely to progress to symptoms or more advanced bradyarrhythmias (e.g., Mobitz type II second-degree AV block in the setting of acute myocardial infarction). If the bradycardia is suspected to be the cause of acute altered mental status, ischemic chest discomfort, acute heart failure, hypotension, or other signs of shock, the patient should receive immediate treatment.

Atropine remains the first-line drug for acute symptomatic bradycardia. The recommended atropine dose for bradycardia is 0.5 mg IV every 3 to 5 minutes to a maximum total dose of 3 mg. Doses of atropine sulfate of less than 0.5 mg may result in paradoxical bradycardia. Atropine will also unlikely be effective in patients who had heart transplantation because the transplanted heart lacks vagal innervation. Since atropine works by reversing the muscarinic effects of the parasympathetic nervous system, it is not the preferred drug of choice for type II second-degree or third-degree AV block or in patients with third-degree AV block with a new wide-QRS complex where the location of block is likely to be more distal than the AV nodes. These bradyarrhythmias are not likely to be responsive to atropine and should be treated with transcutaneous pacing (TCP) or β -adrenergic agonists as temporizing measures while the patient is prepared for transvenous pacing.

If bradycardia is unresponsive to atropine, IV infusion of β -adrenergic agonists (dopamine, epinephrine) can be considered. Dopamine is a catecholamine with both α - and β -adrenergic actions. It can be titrated to more selectively target heart rate or vasoconstriction. At lower doses, dopamine has a more selective effect on inotropy and heart rate; at higher doses (>10 μ g/kg/min), it also has vasoconstrictive effects. Epinephrine, as described previously, is a catecholamine with α - and β -adrenergic actions. Isoproterenol is a β -adrenergic agent with β -1 and β -2 effects, resulting in an increase in heart rate and vasodilation. The recommended adult dose is 2 to 10 μ g/min by IV infusion, titrated to the appropriate heart rate and rhythm response.

TCP can be done through the multifunctional pacing/defibrillating pads. It is painful, and sedation should be considered in all awake patients. TCP should be considered a temporary measure only, and the patient should always be prepared for transvenous pacing. Expert consultation should be obtained as soon as possible. Transesophageal atrial pacing can be effective in treating intraoperative supraventricular bradyarrhythmias such as sinus or junctional bradycardia. This device is compatible with most external pacing devices and defibrillators. However, transesophageal pacing is only effective at pacing the atria, at least in its current configuration. In a patient who has AV conduction issues, such as complete heart block, this intervention is ineffective. Effective and consistent pacing also relies on normal acid-base status and electrolyte concentrations; thus acidemia and electrolyte abnormalities such as severe hyperkalemia need to be corrected if pacing is not successful.

Fig. 86.6 illustrates the bradyarrhythmias treatment algorithm recommended in the 2015 AHA Guidelines for CPR and ECC.

TACHYARRHYTHMIA

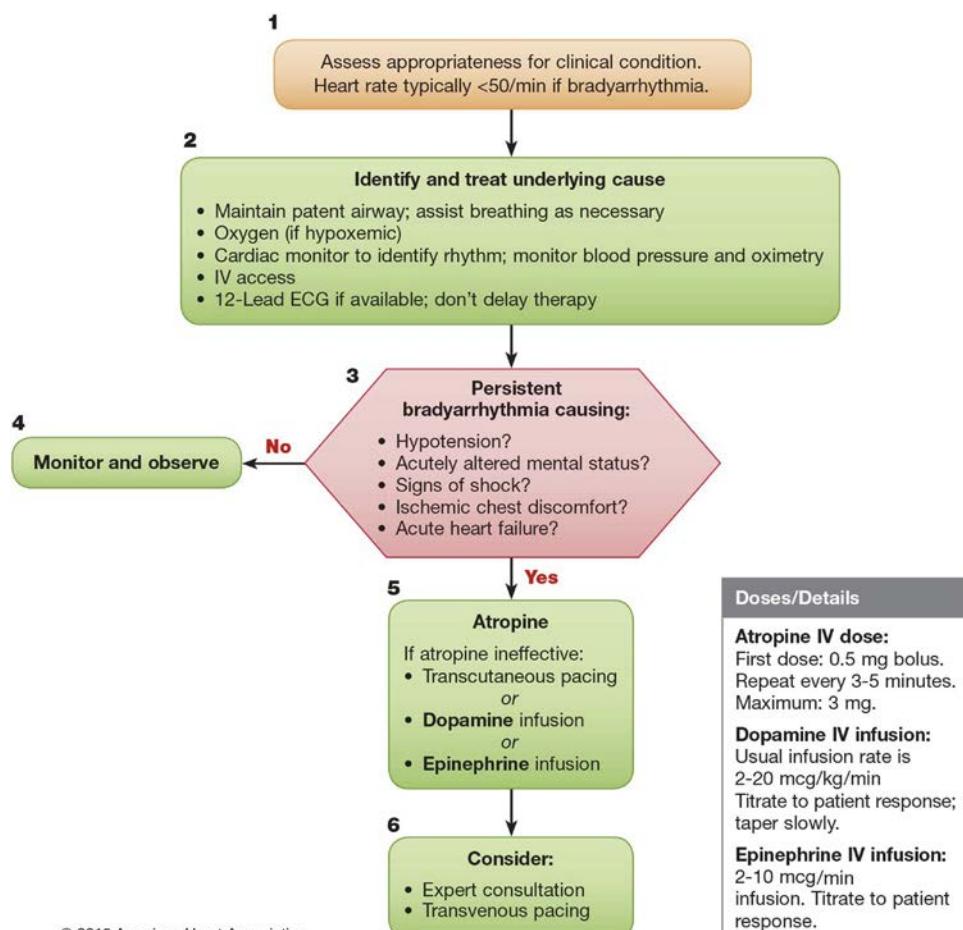
Tachyarrhythmia is defined as an arrhythmia with a rate of more than 100 beats/min, although, as with defining bradycardia, an arrhythmia rate of 150 or more beats/min is more likely to cause clinical symptoms. When encountering patients with tachycardia, efforts should be made to determine whether the tachycardia is the primary cause of the presenting symptoms, or secondary to an underlying condition that is causing both the presenting symptoms and the faster heart rate.

Tachycardia can be classified in several ways, based on the appearance of the QRS complex, heart rate, and regularity. Narrow-complex tachycardias (supraventricular tachycardia [SVT], QRS < 0.12 second) include sinus tachycardia, atrial fibrillation, atrial flutter, AV nodal reentry, accessory pathway-mediated tachycardia, atrial tachycardia (including automatic and reentry forms), multifocal atrial tachycardia, and junctional tachycardia. Wide-QRS-complex tachycardias (QRS ≥ 0.12 second) include VT and VF, SVT with aberrancy, preexcited tachycardias (Wolff-Parkinson-White syndrome), and ventricular-paced rhythms.

Because hypoxemia is a common cause of tachycardia, initial evaluation of any patient with tachycardia, similar to those with bradycardia, should focus on identifying signs of increased work of breathing and oxygen saturation. Patients should be closely monitored and supplemental oxygen provided. A 12-lead ECG better defines the rhythm, but the process should not delay immediate cardioversion if the patient is unstable.

If signs and symptoms persist despite provision of supplementary oxygen and support of airway and ventilation, the provider should assess the patient's degree of instability and determine if the instability is related to the tachycardia. If the patient demonstrates rate-related cardiovascular compromise with signs and symptoms such as acute altered mental status, ischemic chest discomfort, acute heart failure, hypotension, or other signs of shock suspected to be due to a tachyarrhythmia, the provider should proceed to immediate synchronized cardioversion, which can terminate tachyarrhythmias by interrupting the underlying reentrant pathway. The recommended initial biphasic energy dose for cardioversion of atrial fibrillation is 120 to 200 J. Cardioversion of atrial flutter and other SVTs generally requires less energy; an initial energy of 50 J to 100 J is often sufficient. If the initial 50 J shock fails, the provider should increase the dose in a stepwise fashion. Monomorphic VT with a pulse responds well to monophasic or biphasic waveform cardioversion (synchronized) shocks at initial energies of 100 J. If a patient has polymorphic VT, treat the rhythm as VF and deliver high-energy unsynchronized shocks (defibrillation doses).

If the patient with tachycardia is stable, then determine if the patient has a narrow-complex or wide-complex tachycardia, whether the rhythm is regular or irregular, and for wide complexes whether the QRS morphology is monomorphic or polymorphic. Therapy is then tailored accordingly. For regular narrow-complex SVT, vagal maneuvers such as carotid massage or Valsalva maneuver are used first to terminate the arrhythmia. If vagal maneuvers are unsuccessful, then adenosine is the drug of choice for terminating organized rapid supraventricular



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Fig. 86.6 2015 American Heart Association Adult Bradycardia With a Pulse Algorithm. IV, Intravenous. (From Link MS, Berkow LC, Kudenchuk PJ, et al. Part 7: Adult Advanced Cardiovascular Life Support: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S444-S464.)

arrhythmias. Adenosine slows sinoatrial and AV nodal conduction and prolongs refractoriness, which is very effective in terminating paroxysmal SVT (PSVT), the most common cause of which is reentry within the AV node. The drug is also used to diagnose the underlying mechanism in tachyarrhythmias of uncertain origin (e.g., atrial fibrillation, atrial flutter) by inducing transient block of AV nodal conduction. If adenosine or vagal maneuvers fail to convert PSVT, PSVT recurs after such treatment, or these treatments disclose a different form of SVT (such as atrial fibrillation or flutter), it is reasonable to use longer-acting AV nodal blocking agents, such as the nondihydropyridine calcium channel blockers (verapamil and diltiazem) or β -blockers.

Treatable causes of VT should always be sought before or during pharmacologic or electrical interventions. Hypoxemia, hypercapnia, hypokalemia or hypomagnesemia (or both), digitalis toxicity, and acid-base derangements are obvious causes for VT and should be quickly evaluated and corrected if present. If antiarrhythmic therapy is pursued, procainamide, amiodarone, or sotalol are recommended. Importantly, only one drug should be administered; a second drug should not be added without expert consultation. Hypotension is common with all three of these medications.

The evaluation and management of tachyarrhythmias is illustrated in the 2015 ACLS Tachycardia with Pulse

Algorithm (Fig. 86.7). The medications used for tachyarrhythmia are listed in Tables 86.2 and 86.3.

Postresuscitation Interventions

Hypoxemia, ischemia, and reperfusion occurs during cardiac arrest and resuscitation, regardless of cause of cardiac arrest, and this may cause damage to multiple organ systems. Therefore, effective post–cardiac arrest care consists of identification and treatment of the precipitating cause of cardiac arrest combined with the assessment and mitigation of ischemia-reperfusion injury to multiple organ systems. The severity of damage can vary widely among patients and among organ systems within individual patients. Care must be tailored to the particular disease and dysfunction that affect each patient. Therefore, individual patients may require few, many, or all of the specific interventions discussed in the following part of this section.

EMERGENCY PERCUTANEOUS CORONARY INTERVENTION

Acute coronary syndromes are a common etiology for OHCA in adults with no obvious extracardiac cause of arrest and also can precipitate some IHCA. One study examined

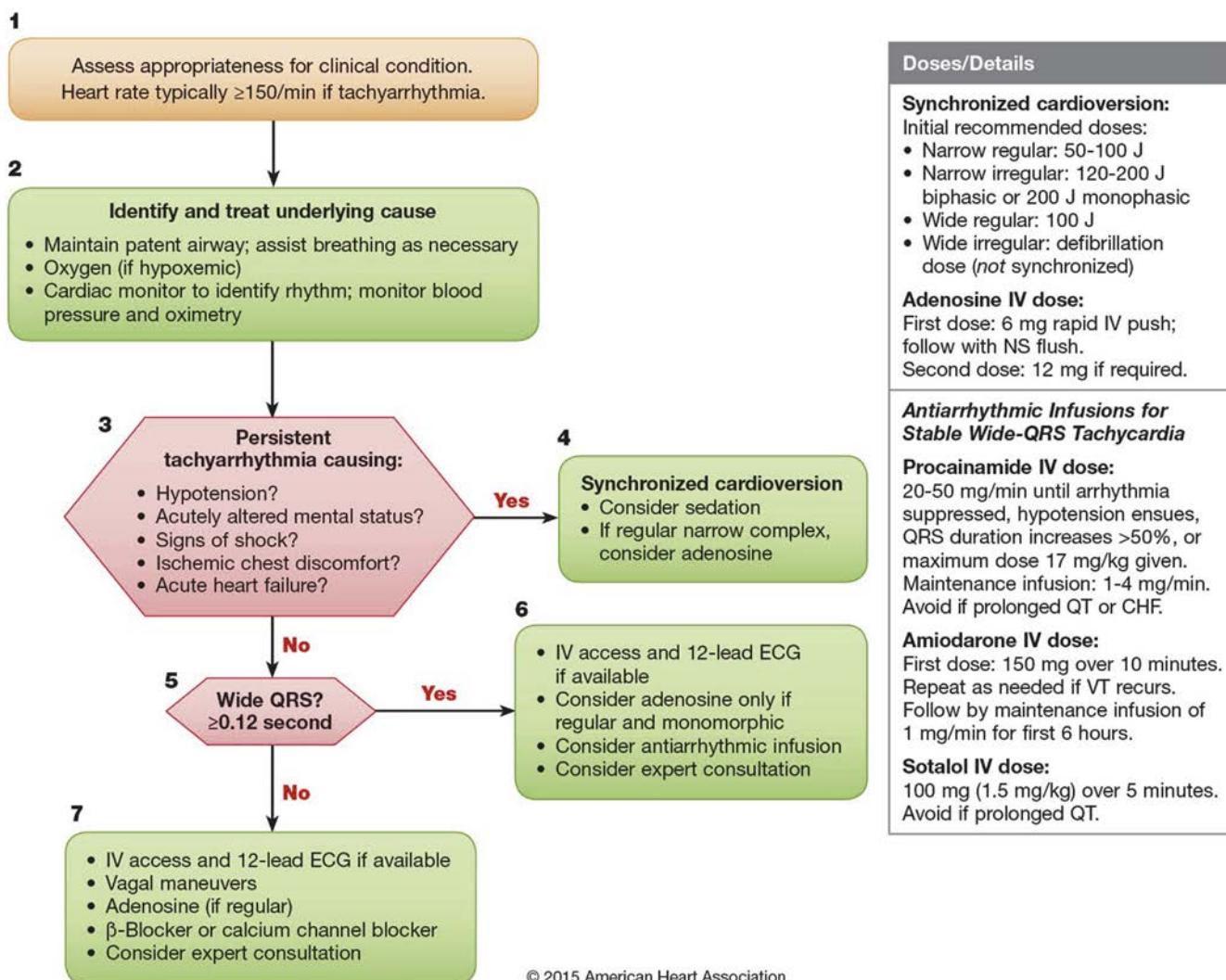


Fig. 86.7 2015 American Heart Association Adult Tachycardia With a Pulse Algorithm. *IV*, Intravenous; *NS*, normal saline; *VT*, ventricular tachycardia. (From Link MS, Berkow LC, Kudenchuk PJ, et al. Part 7: Adult Advanced Cardiovascular Life Support: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S444-S464.)

a consecutive series of post–cardiac arrest patients with suspected cardiovascular cause, and found a coronary artery lesion amenable to emergency treatment in 96% of patients with ST elevation and in 58% of patients without ST elevation during subsequent coronary angiography.⁶⁴ Thus urgent coronary angiography with prompt recanalization of any infarct-related artery is crucially important to improving the patient’s survival, enhancing neurologic outcome, and preventing recurrence of arrest.

Evidence regarding the timing of coronary angiography immediately after cardiac arrest (defined variously, but within 24 hours) is limited to observational studies. Data from studies with more than 3800 patients having ST elevation on ECG after ROSC after cardiac arrest demonstrated a benefit of immediate coronary angiography with improved survival to hospital discharge, while more than half of these studies also demonstrated a benefit with improved neurological outcomes.⁶⁵⁻⁶⁷ Fewer data are available to evaluate coronary angiography in patients without ST elevation on the initial post–cardiac arrest ECG. Two studies demonstrated a benefit with

improved survival to hospital discharge and improved neurologic outcome when patients received immediate coronary angiography.^{65,68} In these studies, the decision to undertake the intervention was influenced by a variety of factors such as patient age, duration of CPR, hemodynamic instability, presenting cardiac rhythm, neurologic status upon hospital arrival, and perceived likelihood of cardiac etiology. The 2015 AHA Guidelines for CPR and ECC recommended that coronary angiography should be performed emergently (rather than later in the hospital stay or not at all) for OHCA patients with suspected cardiac etiology of arrest and ST elevation on ECG. Emergency coronary angiography should be considered for select (e.g., electrically or hemodynamically unstable) adult patients who are comatose after OHCA of suspected cardiac origin but without ST elevation on ECG. Overall, coronary angiography is reasonable in post–cardiac arrest patients where coronary angiography is indicated, regardless of the patient’s mental status. The 2015 acute coronary syndrome algorithm is illustrated in Fig. 86.8.⁶⁹

TABLE 86.2 Summary of Medications Used for Supraventricular Tachycardia

Drug	Characteristics	Indication(s)	Dosing	Side Effects	Precautions or Special Considerations
Adenosine	Endogenous purine nucleoside; briefly depresses sinus node rate and AV node conduction; vasodilator	<ul style="list-style-type: none"> ■ Stable, narrow-complex regular tachycardias ■ Unstable narrow-complex regular tachycardias while preparations are made for electrical cardioversion ■ Stable, regular, monomorphic, wide-complex tachycardia as a therapeutic and diagnostic maneuver 	6 mg IV as a rapid IV push followed by a 20 mL saline flush; repeat if required as 12 mg IV push	Hypotension, broncho-spasm, chest discomfort	Contraindicated in patients with asthma; may precipitate atrial fibrillation, which may be very rapid in patients with WPW; thus a defibrillator should be readily available; reduce dose in post-cardiac transplant patients, those taking dipyridamole or carbamazepine and when administered via a central vein
Diltiazem, Verapamil	Non-dihydropyridine calcium channel blockers; slow AV node conduction and increase AV node refractoriness; vasodilators, negative inotropes	<ul style="list-style-type: none"> ■ Stable, narrow-complex tachycardias if rhythm remains uncontrolled or unconverted by adenosine or vagal maneuvers or if SVT is recurrent ■ Control ventricular rate in patients with atrial fibrillation or atrial flutter 	<p>Diltiazem: Initial dose 15-20 mg (0.25 mg/kg) IV over 2 min; additional 20-25 mg (0.35 mg/kg) IV in 15 min if needed; 5-15 mg/h IV maintenance infusion (titrated to AF heart rate if given for rate control)</p> <p>Verapamil: Initial dose 2.5-5 mg IV given over 2 min; may repeat as 5-10 mg every 15-30 min to total dose of 20-30 mg</p>	Hypotension, bradycardia, precipitation of heart failure	Should only be given to patients with narrow-complex tachycardias (regular or irregular). Avoid in patients with heart failure and preexcited AF or flutter or rhythms consistent with VT
Atenolol, Esmolol, Metoprolol, Propranolol	β-Blockers; reduce effects of circulating catecholamines; reduce heart rate, AV node conduction and blood pressure; negative inotropes	<ul style="list-style-type: none"> ■ Stable, narrow-complex tachycardias if rhythm remains uncontrolled or unconverted by adenosine or vagal maneuvers or if SVT is recurrent ■ Control ventricular rate in patients with atrial fibrillation or atrial flutter ■ Certain forms of polymorphic VT (associated with acute ischemia, familial LQTS, catecholaminergic) 	<p>Atenolol (β1 specific blocker) 5 mg IV over 5 min; repeat 5 mg in 10 min if arrhythmia persists or recurs</p> <p>Esmolol (β1 specific blocker with 2- to 9-min half-life) IV loading dose 500 mcg/kg (0.5 mg/kg) over 1 min, followed by an infusion of 50 mcg/kg per min (0.05 mg/kg/min); if response is inadequate, infuse second loading bolus of 0.5 mg/kg over 1 min and increase maintenance infusion to 100 mcg/kg (0.1 mg/kg) per min; increment; increase in this manner if required to maximum infusion rate of 300 mcg/kg [0.3 mg/kg] per min</p> <p>Metoprolol (β1 specific blocker) 5 mg over 1-2 min repeated as required every 5 min to maximum dose of 15 mg</p> <p>Propranolol (nonselective β-blocker) 0.5-1 mg over 1 min, repeated up to a total dose of 0.1 mg/kg if required</p>	Hypotension, bradycardia, precipitation of heart failure	Avoid in patients with asthma, obstructive airway disease, decompensated heart failure and pre-excited atrial fibrillation or flutter
Procainamide	Sodium and potassium channel blocker	■ Preexcited atrial fibrillation	20-50 mg/min until arrhythmia suppressed, hypotension ensues, or QRS prolonged by 50%, or total cumulative dose of 17 mg/kg; or 100 mg every 5 min until arrhythmia is controlled or other conditions described above are met	Bradycardia, hypotension, torsades de pointes	Avoid in patients with QT prolongation and CHF
Amiodarone	Multichannel blocker (sodium, potassium, calcium channel, and noncompetitive α/β-blocker)	<ul style="list-style-type: none"> ■ Stable irregular narrow-complex tachycardia (atrial fibrillation) ■ Stable regular narrow-complex tachycardia ■ To control rapid ventricular rate due to accessory pathway conduction in pre-excited atrial arrhythmias 	<p>150 mg given over 10 min and repeated if necessary, followed by a 1 mg/min infusion for 6 h, followed by 0.5 mg/min.</p> <p>Total dose over 24 h should not exceed 2.2 g.</p>	Bradycardia, hypotension, phlebitis	

Continued

TABLE 86.2 Summary of Medications Used for Supraventricular Tachycardia—cont'd

Drug	Characteristics	Indication(s)	Dosing	Side Effects	Precautions or Special Considerations
Digoxin	Cardiac glycoside with positive inotropic effects; slows AV node conduction by enhancing parasympathetic tone; slow onset of action	<ul style="list-style-type: none"> ■ Stable, narrow-complex regular tachycardias if rhythm remains uncontrolled or unconverted by adenosine or vagal maneuvers or if SVT is recurrent ■ Control ventricular rate in patients with atrial fibrillation or atrial flutter 	8-12 mcg/kg total loading dose, half of which is administered initially over 5 min, and remaining portion as 25% fractions at 4- to 8-h intervals	Bradycardia	Slow onset of action and relative low potency renders it less useful for treatment of acute arrhythmias

AF, Atrial fibrillation; AV, atrioventricular; CHF, congestive heart failure; IV, intravenous; LQTS, long QT syndrome; SVT, supraventricular tachycardia; VT, ventricular tachycardia; WPW, Wolff-Parkinson-White syndrome.

From <https://eccguidelines.heart.org/index.php/tables/2010-iv-drugs-used-for-tachycardia-2/>.

TABLE 86.3 Summary of Medications Used for Ventricular Tachycardia

Drug	Characteristics	Indication(s)	Dosing	Side Effects	Precautions or Special Considerations
Procainamide	Sodium and potassium channel blocker	<ul style="list-style-type: none"> ■ Hemodynamically stable monomorphic VT 	20-50 mg/min until arrhythmia suppressed, hypotension ensues, or QRS prolonged by 50%, or total cumulative dose of 17 mg/kg; or 100 mg every 5 min until arrhythmia is controlled or other conditions described previously are met	Bradycardia, hypotension, torsades de pointes	Avoid in patients with QT prolongation and CHF
Amiodarone	Multichannel blocker (sodium, potassium, calcium channel, α - and noncompetitive β -blocker)	<ul style="list-style-type: none"> ■ Hemodynamically stable monomorphic VT ■ Polymorphic VT with normal QT interval 	150 mg given over 10 min and repeated if necessary, followed by a 1 mg/min infusion for 6 h, followed by 0.5 mg/min. Total dose over 24 h should not exceed 2.2 g.	Bradycardia, hypotension, phlebitis	
Sotalol	Potassium channel blocker and nonselective β -blocker	<ul style="list-style-type: none"> ■ Hemodynamically stable monomorphic VT 	In clinical studies 1.5 mg/kg infused over 5 min; however, U.S. package labeling recommends any dose of the drug should be infused slowly over a period of 5 h	Bradycardia, hypotension, torsades de pointes	Avoid in patients with QT prolongation and CHF
Lidocaine	Relatively weak sodium channel blocker	<ul style="list-style-type: none"> ■ Hemodynamically stable monomorphic VT 	Initial dose range from 1 to 1.5 mg/kg IV; repeated if required at 0.5-0.75 mg/kg IV every 5-10 min up to maximum cumulative dose of 3 mg/kg; 1-4 mg/min (30-50 mcg/kg/min) maintenance infusion	Slurred speech, altered consciousness, seizures, bradycardia	
Magnesium	Cofactor in variety of cell processes including control of sodium and potassium transport	<ul style="list-style-type: none"> ■ Polymorphic VT associated with QT prolongation (torsades de pointes) 	1-2 g IV over 15 min	Hypotension, CNS toxicity, respiratory depression	Follow magnesium levels if frequent or prolonged dosing required, particularly in patients with impaired renal function

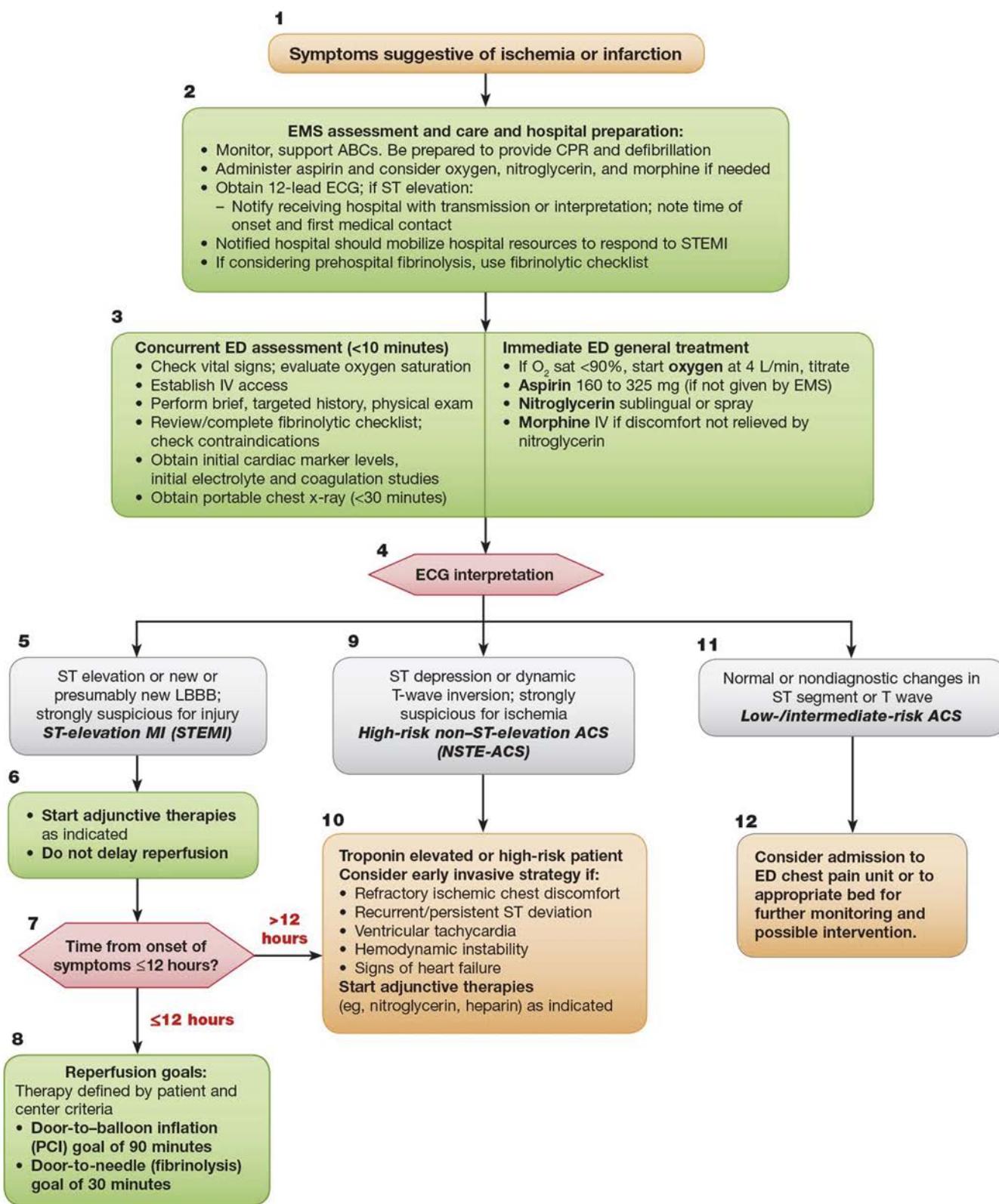
CHF, Congestive heart failure; CNS, central nervous system; IV, intravenous; VT, ventricular tachycardia.

From <https://eccguidelines.heart.org/index.php/tables/2010-iv-drugs-used-for-tachycardia-2/>.

TARGETED TEMPERATURE MANAGEMENT

Devastating neurologic injury, particularly anoxic brain injury, is frequent in post–cardiac arrest patients. Over the years, numerous pharmacologic interventions, including steroids, barbiturates, and nimodipine, have been tried for cerebral protection in this patient population with unsatisfactory results. This was until the seminal publications

describing the use of systemic hypothermia to 33°C within 2 hours of OHCA and maintained for 12 or 24 hours, which showed improved outcomes among survivors.^{70,71} The mechanism of cerebral protection with hypothermia is complex, but is suggested to include its effect on the cerebral metabolic rate. For every 1°C reduction in brain temperature, a 6% reduction in cerebral metabolic rate is



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Fig. 86.8 2015 American Heart Association Acute Coronary Syndrome Algorithm. ABC, Airway, breathing, circulation; CPR, cardiopulmonary resuscitation; EMS, emergency medical services; IV, intravenous. (From O'Connor RE, Al Ali AS, Brady WJ, et al. Part 9: Acute Coronary Syndromes: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S483–S500. <https://eccguidelines.heart.org/index.php/circulation/cpr-ecc-guidelines-2/part-9-acute-coronary-syndromes/>.)

observed. By limiting the metabolic demand and decreasing the utilization of oxygen and glucose, targeted temperature management (TTM) reduces the risk of energy depletion, preserving the ion channel's integrity and decreasing the intracellular calcium influx that can trigger neuronal apoptotic pathways.⁷² Indeed, animal models have been used to evaluate the mitigating effects of hypothermia on pathways leading to excitotoxicity, apoptosis, inflammation, and free radical production, as well as its significance in preserving the blood–brain barrier integrity, neuronal viability, and neurologic outcome.⁷³ TTM encompasses therapeutic hypothermia, controlled normothermia, and treatment of fever.

The HACA trial was the first study to show clinical benefit in a focused patient cohort.⁷¹ Following the publication of this study, a number of other studies also evaluated induced hypothermia after cardiac arrest, which gained widespread use and is now advocated by international guidelines. Of note, the Target Temperature Management After Cardiac Arrest (or the TTM) trial⁷⁴ found no difference in neurologic outcome when comparing 939 OHCA victims after cooling to 33°C versus controlled temperature maintenance at 36°C, but both arms of this trial involved a form of TTM as opposed to no TTM. Consequently, the TTM trial might underscore the importance of active temperature management after ROSC. The 2015 AHA Guidelines for CPR and ECC recommend TTM in all comatose (i.e., lack of meaningful response to verbal commands) adult patients with ROSC after cardiac arrest, irrespective of the initial rhythm (shockable or not). A target temperature between 32°C and 36°C is recommended for at least 24 hours. It is also recommended to continue to monitor the temperature and maintain normothermia (treat fever) beyond this window. Prognostication should not occur until 72 hours after ROSC, or if TTM is provided, 72 hours after completion of TTM.

Experimental studies also suggest that the greatest benefit of hypothermia in neuroprotection is achieved when it is effectively applied within hours of the event, with likely benefit being within 6 hours or earlier after the insult. Although human studies have yet not confirmed the critical window for effective implementation of TTM to improve neurologic outcome after cardiac arrest, they have established that the target temperature is more rapidly obtained in cohorts where intranasal, surface, or intravascular temperature-modulating devices (servo-controlled or inbuilt feedback mechanisms) were used, as compared to surface cooling with air-cooling blankets, cooling fans, or ice cooling packs. There was also a lower likelihood to overshoot the target temperature when these devices were employed. Intravascular heat exchange catheters are currently the most efficient technique for achieving the target temperature within a short period after ROSC, and can also be used in combination with surface-cooling modalities.⁷⁵ Their use is nevertheless limited by their invasive nature and associated risks such as vascular injury, bleeding, or thrombosis. In addition, no benefit in survival has been shown using these more invasive devices. The use of cold saline as an adjunctive therapy in the prehospital setting is not recommended because the data from the RINSE trial showed that prehospital cold IV fluids in victims of cardiac arrest did not

improve outcome, but resulted in an increased incidence of pulmonary edema during the first 24 hours after ROSC.⁷⁶

POSTRESUSCITATION OXYGEN AND VENTILATION THERAPY

Hyperoxia in preclinical studies was associated with worsening oxidative stress, free radical production, and worsened organ function.⁷⁷ Importantly, Kilgannon and colleagues reported an association between hyperoxia and in-hospital mortality after resuscitation from cardiac arrest.⁷⁸ Consequently, the AHA guidelines recommend that once reliable oxygenation and ventilation monitors are in place, the fraction of inspired oxygen (FiO₂) should be decreased to avoid hyperoxia.^{69,77} It is worth noting that in the immediate post-ROSC period, the intense systemic vasoconstriction may make it challenging for pulse oximetry to work optimally; thus access and use of arterial blood gases to guide therapy should be part of the management strategy.

Post–cardiac arrest patients are at increased risk for developing ARDS. Some of the contributing factors include aspiration pneumonia, pulmonary contusions after aggressive CPR, ventilator-associated lung injury, and the pulmonary manifestations of the post–cardiac arrest syndrome. The optimal mechanical ventilation strategy after cardiac arrest has, nevertheless, not been well defined. Although more focused studies are still needed, it is suggested that patients with ARDS should be ventilated according to the Acute Respiratory Distress Syndrome Network (ARDSNet) low-tidal volume strategy.⁷⁹

Excessive hyperventilation and hypocarbia can also adversely affect the outcome, as it can lead to cerebral vasoconstriction and worsening blood flow, in particular in areas with no reflow or hypoperfusion after ROSC. A recent systematic review evaluating data from at least eight studies found that both hypocarbia and hypercarbia are associated with worse neurologic outcomes in the post–cardiac arrest syndrome patient.²³ Therefore, it is recommended that after resuscitation from cardiac arrest, the PaCO₂ be maintained within the normal physiologic range (end-tidal CO₂ 30–40 mm Hg or PaCO₂ 35–45 mm Hg), taking into account any temperature correction.⁶⁹

GLYCEMIC CONTROL IN THE POST–CARDIAC ARREST PATIENT

Hyperglycemia is frequently encountered in survivors of cardiac arrest because of a combination of several factors including the effect of counter-regulatory hormones in the immediate post-ROSC period. Poor glycemic control has been associated with poor neurologic outcome in critically ill patients. Hyperglycemia is thought to cause secondary injury by exacerbating intracellular acidosis, increasing free radical formation, increasing extracellular glutamate levels, and disrupting the blood–brain barrier. On the other hand, tight glucose control at low levels has also been associated with increased frequency of hypoglycemic episodes and poor patient outcome.⁸⁰ Although the data on glycemic control in the post–cardiac arrest patient are not definitive, it is reasonable to monitor blood glucose concentration and avoid extreme levels of blood glucose in this population.

DETERMINE THE CAUSE AND EXTENT OF INJURY

AFTER CARDIAC ARREST

Laboratory Testing

Laboratory testing may provide insight into the etiology of cardiac arrest, help identify potentially reversible and/or intervenable factors, and may allow the evaluation of the extent of end-organ damage. In addition to the standard laboratory tests such as a complete blood count, electrolyte and lactate levels, arterial blood gases, and cardiac enzymes, it is reasonable to obtain a repeat ECG to identify ischemic changes and direct management toward emergency reperfusion therapy. Arrhythmias are not unusual in the post–cardiac arrest patient and, if not managed appropriately, may place the patient at risk for recurrent arrest. It is worth noting that besides coronary ischemia etiology, cardiomyopathies and electrical conduction abnormalities constitute the major etiologies for cardiac arrest. A prolonged QTc interval may reflect a primary arrhythmia such as Brugada syndrome, congenital QT prolongation syndromes, or a multitude of acquired etiologies of prolonged QTc in critically ill patients, including medications, hypothermia, electrolyte abnormalities, and bradycardia. In select patients, toxicology testing may be of value to rule out cocaine or methamphetamine intoxication. Cardiopulmonary collapse may also be precipitated by overdose of antidepressants, sedatives, and opioids, leading to profound hypoxemia triggering cardiac arrest.

Chest Radiographs

The value attributed to the diagnostic yield of chest radiographs has diminished over the past decade. However, radiographs can be valuable for rapid diagnosis of conditions such as a pneumothorax, or for confirmation of the position of the ETT and central venous catheters. Lung parenchymal pathology and mediastinal pathology should prompt other imaging modalities, such as computed tomography (CT) imaging.

Computed Tomography Imaging

CT imaging can be valuable to determine if pulmonary embolus is present and to examine the presence and extent of pulmonary aspiration or edema after resuscitation from cardiac arrest. CT imaging of the brain can also help identify the presence of intracranial hemorrhage, larger areas of cerebral ischemia, or cerebral edema.

Magnetic Resonance Imaging of the Brain

The role of magnetic resonance imaging (MRI) in the evaluation of the post–cardiac arrest patient is discussed in this section.

Echocardiography and Critical Care

Ultrasonography

The widespread availability of echocardiographic equipment and its proficient use in intensive care have enabled early identification of important treatable causes of cardiac arrest. Examples include:

- Pericardial tamponade. It is worth noting that the size of pericardial effusion, which is a relatively common finding, is not diagnostic of tamponade, as the rate of fluid

accumulation is more likely to determine tamponade pathophysiology. Usually the chamber with the lowest pressure, the right atrium, begins to collapse during ventricular diastole and can be visualized by echocardiography at the time of diagnosis.

- Acute myocardial ischemia with new regional wall motion abnormalities.
- Acute PE. Echocardiography can be very useful in the early diagnosis of PE, especially when the patient is too unstable to be transported for CT scans. Important echocardiographic findings include the demonstration of the McConnell sign (akinesia of the mid free wall but normal motion at the RV apex) or other RV strain patterns such as an RV diameter greater than 30 mm in the parasternal long-axis view, or an increase in the area of the RV relative to the LV in the apical four-chamber view. Flattening of the interventricular septum is another feature (D-shaped septum) that suggests the diagnosis of acute massive PE.
- Tension pneumothorax. Ultrasonography offers a higher sensitivity to the detection of an otherwise clinical diagnosis of tension pneumothorax. The quick demonstration of the “seashore sign,” “B-lines,” comet tails, and the “lung pulse” confirms the apposition of the visceral and parietal pleura and excludes pneumothorax.
- Severe hypovolemia. Inadequate circulating intravascular volume is frequently a precipitating cause of cardiac arrest of nonmyocardial etiology. Ultrasound/echocardiography allows for rapid evaluation of intravascular fluid status and response to a fluid challenge to guide management in the post–cardiac arrest patient. However, one has to be aware of the pitfalls of assessing volume status based on static indices.

TERMINATION OF RESUSCITATION EFFORTS— INDICATORS OF POOR OUTCOME POST-RETURN OF SPONTANEOUS CIRCULATION

The 2015 AHA Guidelines for CPR and ECC discussed the use of clinical examination, electrophysiologic measurements, imaging studies, and evaluation of blood or cerebrospinal fluid markers of brain injury to estimate the prognosis for neurologic improvement in patients who are comatose after cardiac arrest and the decision to terminate resuscitative efforts. Because sedatives or neuromuscular blockers received during TTM may be metabolized more slowly in post–cardiac arrest patients, and injured brains may be more sensitive to the depressant effects of various medications, residual sedation or paralysis can confound the accuracy of clinical examinations. Multiple investigations suggest that it is necessary to wait to prognosticate for a minimum of 72 hours after ROSC to minimize the rate of false-positive results in patients who had not undergone TTM and to wait for some period of time after return of normothermia for those using TTM. In many cases, clinicians choose to complete their final evaluation for prognostication 5 to 7 days after the arrest.

Studies have shown that factors such as the patient's pre-arrest comorbidities are associated with poor survival and outcome. The initial cardiac rhythm, the no-flow (arrest) and low-flow (CPR) times, and the quality of chest compressions (as indicated by the ETCO_2) are also associated with patient outcome. Clinical examinations, such as loss

of corneal and pupillary light reflexes, extensor posturing, and the presence of status myoclonus, also point to a poor prognosis. In comatose patients who are treated with TTM or not, the absence of pupillary reflex to light at 72 hours or more after cardiac arrest has the lowest false-positive rate (FPR) of 0% to 1% to predict poor neurologic outcome compared with other clinical examination indicators.⁶⁹ It is also important to distinguish myoclonus from status myoclonus (continuous, repetitive myoclonic jerks lasting more than 30 minutes) because the presence of any myoclonus is not a reliable predictor of poor functional recovery, but status myoclonus during the first 72 hours after cardiac arrest achieved an FPR of 0%.⁶⁹

EEG has been used widely in the diagnosis of seizures and prognostication after cardiac arrest, even though the lack of standardized EEG terminology continues to limit its use in research and practice. In comatose post–cardiac arrest patients who are treated with TTM, persistent absence of EEG reactivity to external stimuli at 72 hours after cardiac arrest and persistent burst suppression on EEG after rewarming, has a FPR of 0%. Intractable and persistent (more than 72 hours) status epilepticus in the absence of EEG reactivity to external stimuli is also an indicator of poor outcome. In comatose post–cardiac arrest patients who are not treated with TTM, the presence of burst suppression on EEG at 72 hours or more after cardiac arrest, in combination with other predictors, has a FPR of 0%, and can be used to predict poor outcome. In patients who are comatose after resuscitation from cardiac arrest regardless of treatment with TTM, bilateral absence of the N20 somatosensory-evoked potentials wave 24 to 72 hours after cardiac arrest or after rewarming predicts poor outcome (FPR 1%).

Brain imaging studies, including CT or MRI scans, can define structural brain injury or detect focal injury. In patients who are comatose after resuscitation from cardiac arrest and not treated with TTM, the presence of a marked reduction of the gray-white ratio on brain CT obtained within 2 hours after cardiac arrest could be used to predict poor outcome, as well as extensive restriction of diffusion on brain MRI at 2 to 6 days after cardiac arrest. However, it needs to be noted that both imaging modalities have higher FPRs and wider confidence intervals compared with clinical examination predictors, and thus should be used in combination with other established predictors to predict a poor neurologic outcome. There is currently no established role of laboratory biomarkers of brain injury in predicting neurologic outcome.

Pediatric Resuscitation

Pediatric cardiac arrest portends similar poor prognosis as adults. Data from the 2005 to 2007 Resuscitation Outcomes Consortium, a registry of 11 U.S. and Canadian emergency medical systems, showed age-dependent discharge survival rates of 3.3% for infants (younger than 1 year), 9.1% for children (1–11 years), and 8.9% for adolescents (12–19 years).⁸¹ More recently, published data from this network demonstrated 8.3% survival to hospital discharge across all age groups.⁸² Outcomes from pediatric IHCA, however, have markedly improved over the past decade. From 2001 to 2009, rates of pediatric IHCA survival to hospital

discharge improved from 24% to 39%.⁸³ Prolonged CPR is not always futile, with 12% of patients who receive CPR for more than 35 minutes surviving to discharge and 60% of those survivors having a favorable neurologic outcome.⁸⁴ This improvement in survival rate from IHCA can be attributed to multiple factors, including emphasis on high-quality CPR and advances in postresuscitation care.

Pediatric resuscitation requires clinical expertise including understanding of its unique pathophysiology, clinical implications, and therapeutic considerations. Even though asphyxiation is the leading cause of pediatric cardiac arrest and warrants initial focused investigation and management, the pediatric resuscitation guidelines closely follow the adult guidelines in order to facilitate training, retention, and implementation of resuscitation guidelines. For example, minimally interrupted and effectively performed chest compressions, ventilation, and prompt defibrillation are emphasized to improve outcome from cardiac arrest and should always be the focus of resuscitation effort.

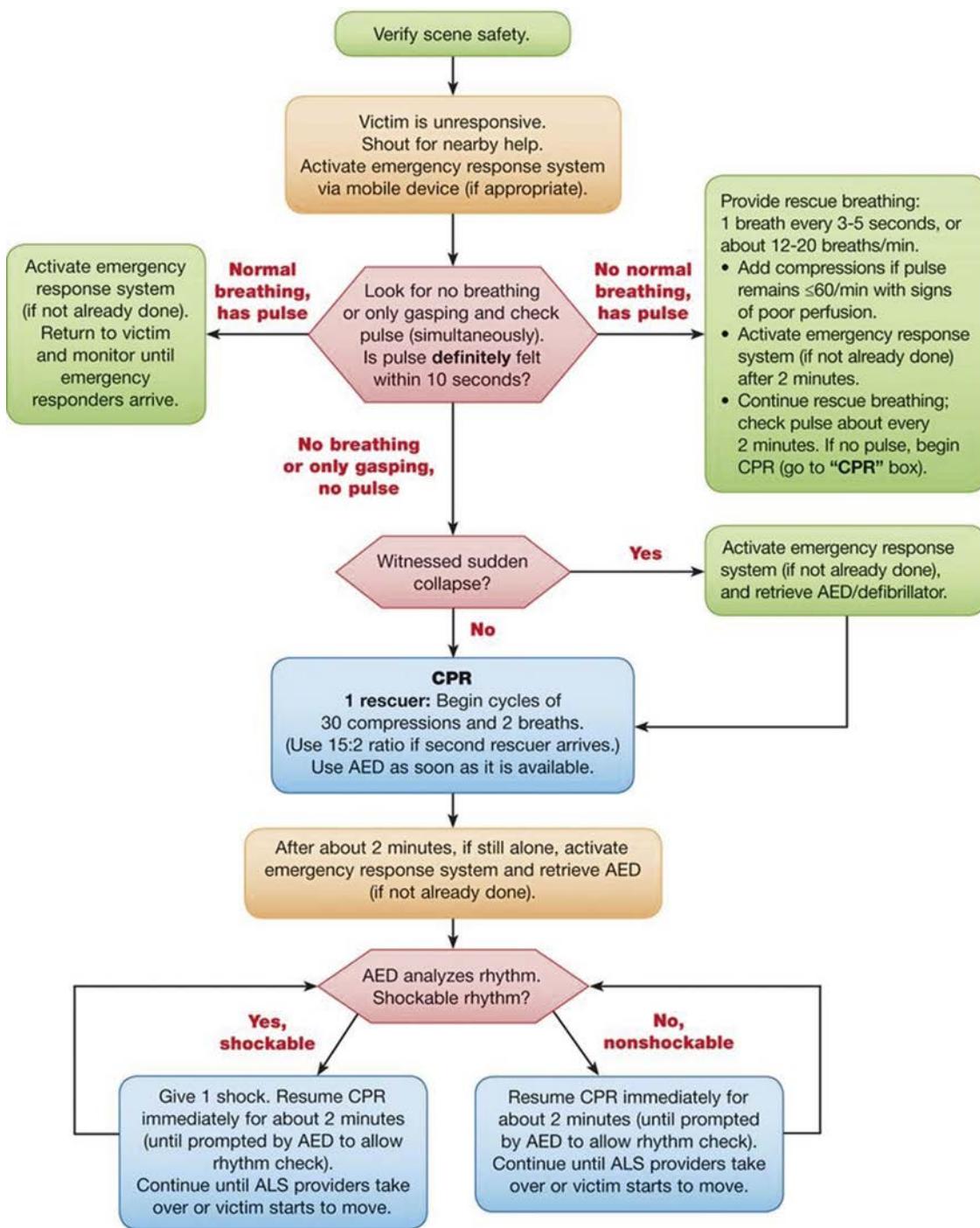
PEDIATRIC BASIC LIFE SUPPORT

Asphyxiation is a much more common cause of cardiac arrest in infants and children than a primary cardiac event, and airway management and ventilation are therefore more important during the resuscitation of children. Data from animal studies^{85,86} and pediatric studies^{87,88} suggest that resuscitation outcomes for asphyxial cardiac arrest are better with a combination of ventilation and chest compressions. Therefore, historically, the preferred sequence of CPR was A-B-C (Airway-Breathing-Circulation). However, a universal CPR algorithm for victims of all ages minimizes the complexity of CPR and offers consistency in CPR training. In addition, there is inadequate data to identify which resuscitation method offers better survival in this population: beginning with ventilations (A-B-C) first or with chest compressions (C-A-B). The 2015 AHA Guidelines for CPR and ECC maintained the changes of the 2010 recommendations that the C-A-B sequence should be used to decrease the time to initiation of chest compressions and reduce “no blood flow” time in acute pediatric cardiac arrest.

The 2015 AHA Guidelines for CPR and ECC on pediatric BLS algorithms separated one-person from two-person or more healthcare provider CPR to better guide rescuers through the initial stages of resuscitation (Figs. 86.9 and 86.10).⁸⁹ In an era where cellular telephones with speakers are common, this technology can allow a single rescuer to activate the emergency response system while beginning CPR. These algorithms continue to emphasize the importance of obtaining an AED quickly in a sudden, witnessed collapse, because such an event is likely to have a cardiac etiology.

The 2015 AHA Guidelines for CPR and ECC on pediatric BLS continue to emphasize the five components of high-quality CPR, which includes:

- Ensuring chest compressions of adequate rate
- Ensuring chest compressions of adequate depth
- Allowing full chest recoil between compressions
- Minimizing interruptions in chest compressions
- Avoiding excessive ventilation

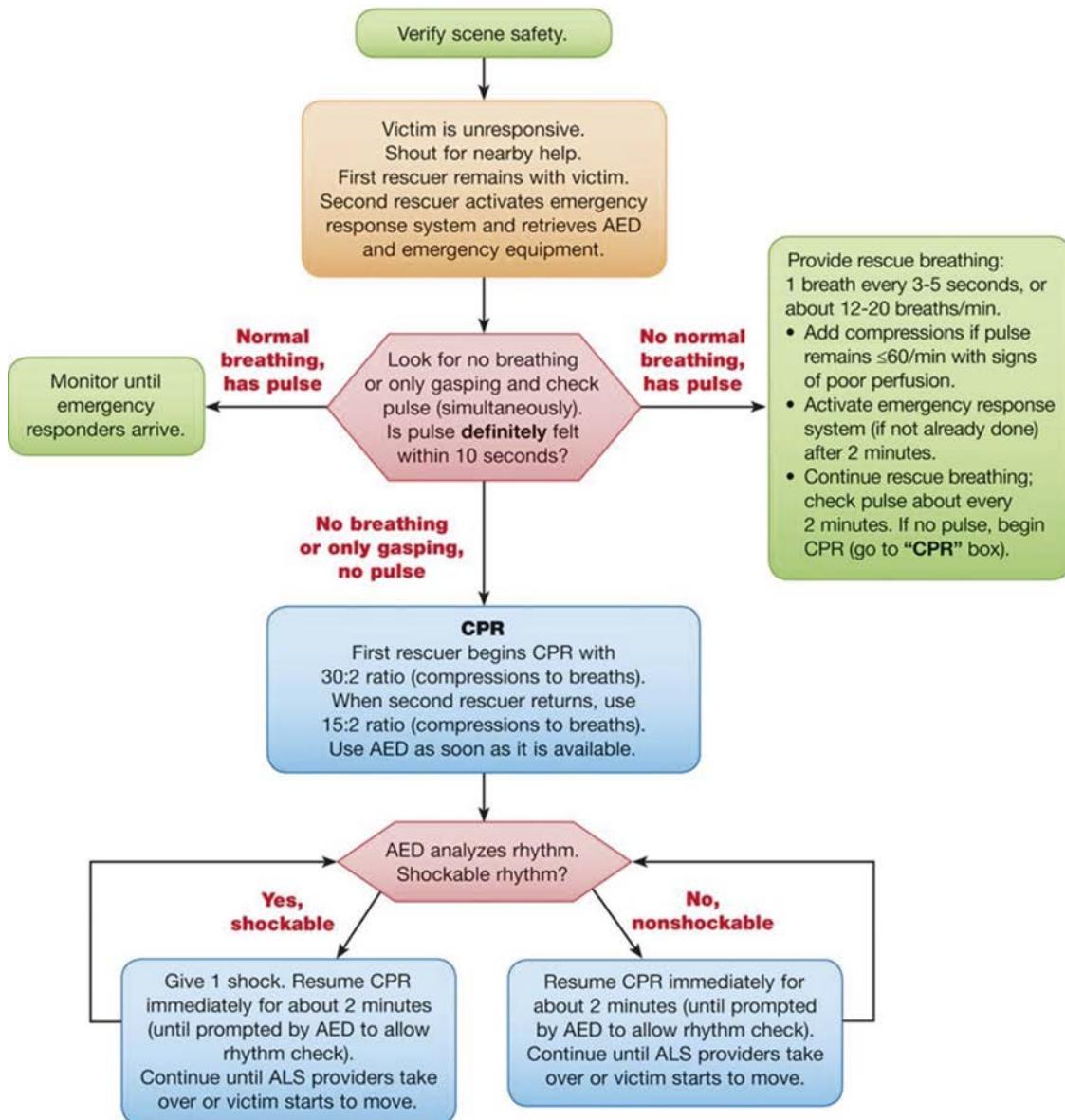


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Fig. 86.9 2015 American Heart Association Pediatric Cardiac Arrest Algorithm for Single Rescuer. AED, Automated external defibrillator; CPR, cardiopulmonary resuscitation. (From Atkins DL, Berger S, Duff JP, et al. Part 11: Pediatric Basic Life Support and Cardiopulmonary Resuscitation Quality: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S519-525.)

The guidelines recommend the same chest compression rate as in adults: 100/min to 120/min. In infants, the rescuer should place two fingers just below the infra-mammary line on the sternum. In children, chest compressions should be performed by compressing the lower half of the sternum (avoiding the xiphoid process) with one or two hands. The guidelines also recommend that for pediatric patients (birth to the onset of puberty) the depth of chest compression should be at least one-third

the anterior-posterior diameter of the chest. This equates to approximately 1.5 inches (4 cm) in infants to 2 inches (5 cm) in children. Once children have reached puberty, the recommended adult compression depth of at least 5 cm, but no more than 6 cm, is used for the adolescent of average adult size. Conventional CPR (chest compressions and rescue breaths) should be provided for pediatric cardiac arrests. The guidelines also recommended the use of feedback devices to help the rescuer optimize adequate



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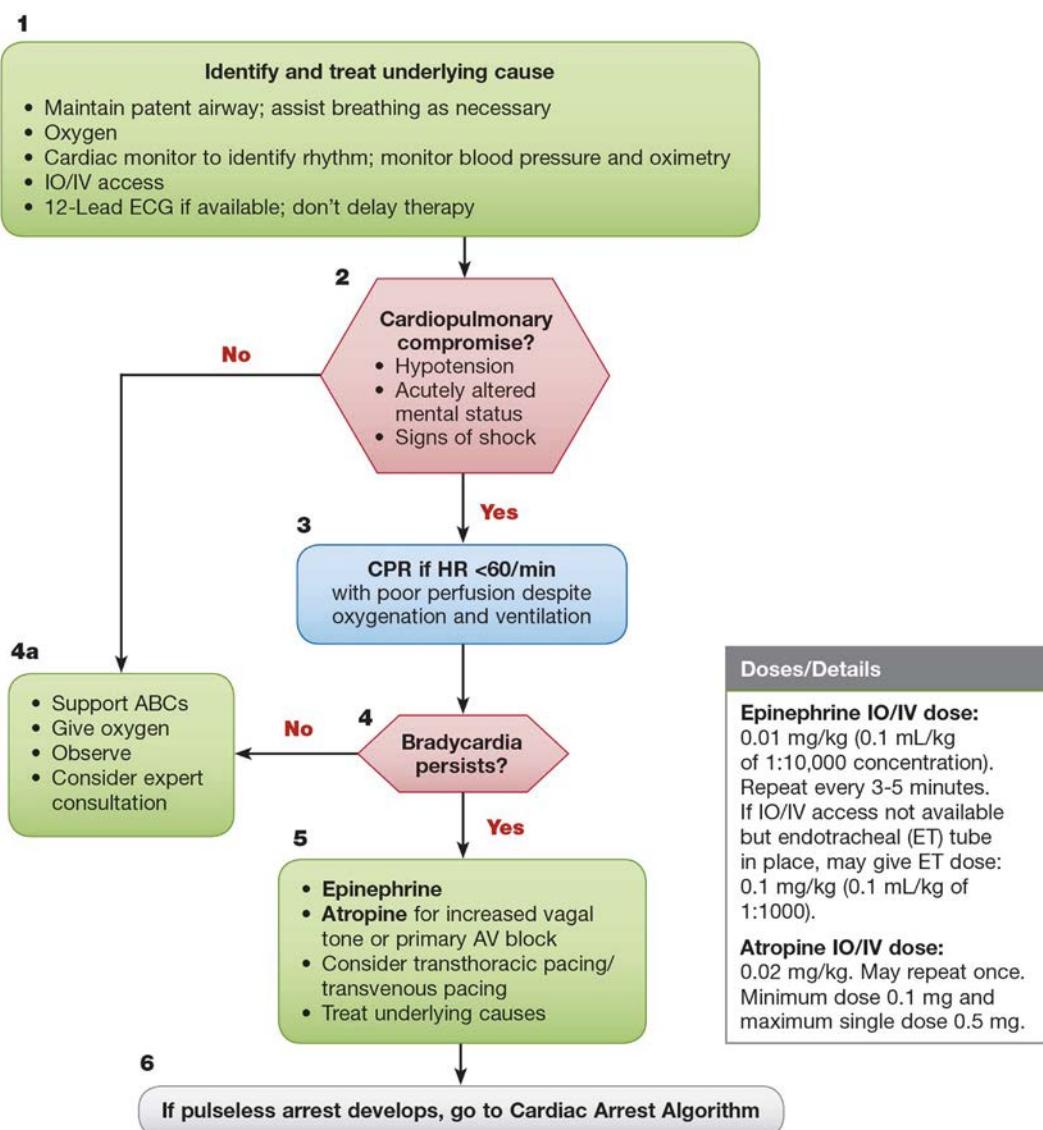
Fig. 86.10 2015 American Heart Association Pediatric Cardiac Arrest Algorithm for Two or More Rescuers. AED, Automated external defibrillator; CPR, cardiopulmonary resuscitation. (From Atkins DL, Berger S, Duff JP, et al. Part 11: Pediatric Basic Life Support and Cardiopulmonary Resuscitation Quality: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S519–S525.)

chest-compression rate and depth. End-tidal CO_2 (ETCO₂) monitoring may evaluate the quality of chest compressions, but specific values to guide therapy have not been established in children. For patients with invasive hemodynamic monitoring in place at the time of cardiac arrest, it may be reasonable for rescuers to use blood pressure to guide CPR quality.

The asphyxial nature of the majority of pediatric cardiac arrests necessitates ventilation as part of effective CPR. This survival benefit has been further supported by one recent large observational study where CPR using chest compressions with rescue breaths had higher survival to discharge rates than either no CPR or chest compression-only CPR.⁹⁰ However, because compression-only CPR is effective in patients with a primary cardiac event, if rescuers are unwilling or

unable to deliver breaths, compression-only CPR is recommended for infants and children in cardiac arrest.

Sudden witnessed collapse in a child is likely to be from VF. For infants, a manual defibrillator is preferred when a shockable rhythm is identified by a trained healthcare provider. An AED with a pediatric attenuator and pediatric defibrillation pads is also preferred for children under 8 years of age. Pediatric defibrillator pads should be applied in the anteroposterior position. In pediatric cardiac arrest, initial defibrillation energy is 2 J/kg and increased to 4 J/kg if a second shock is indicated. For subsequent energy levels, a dose of 4 J/kg may be reasonable and higher energy levels may be considered, but should not exceed 10 J/kg or the adult maximum dose. If no pediatric defibrillator is available, then an adult AED should be applied and used without hesitation.



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Fig. 86.11 2015 American Heart Association Pediatric Bradycardia With a Pulse and Poor Perfusion Algorithm. ABC, Airway, breathing, circulation; AV, atrioventricular; CPR, cardiopulmonary resuscitation; IO, intraosseous; IV, intravenous. (From de Caen AR, Berg MD, Chameides L, et al. Part 12: Pediatric Advanced Life Support: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S526–S542.)

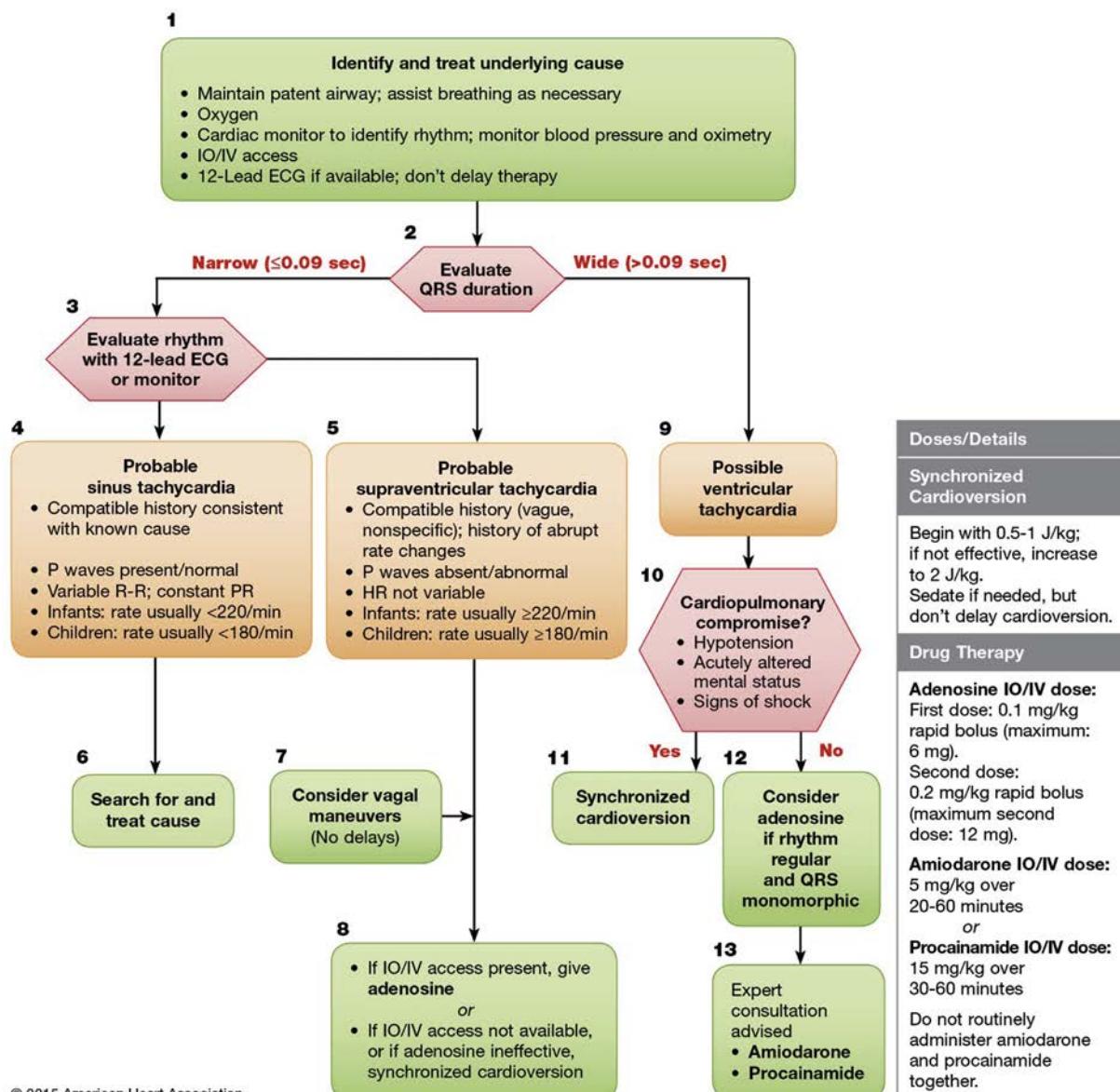
PEDIATRIC ADVANCED LIFE SUPPORT

Given the fact that asphyxiation is a much more common etiology of cardiac arrest in infants and children than primary cardiac events, effective basic and advanced airway management, oxygenation, and ventilation are of utmost importance. However, as with adult cardiac arrests, airway management should not cause prolonged interruption of chest compressions. Similarly, the placement of an advanced airway warrants confirmation of placement using a CO₂ detector and bilateral breath sounds. If the infant or child is intubated, ventilate at a rate of about 1 breath every 6 to 8 seconds (8–10 times/min) without interrupting chest compressions.

Because vascular access can be challenging in critically ill children and circulating medication levels between IV and intraosseous (IO) routes are equivalent, IO access is often

pursued as an alternative in these patients. All resuscitation medications and blood products can be injected into IO catheters. Because of the resistance to fluid flow from the IO catheter into the IO space, fluids must be pressurized to carry fluid into circulation.

As in adults, ECG monitoring permits the immediate recognition of the arrest rhythm or the prearrest rhythm. Prompt intervention and correction in the latter event may prevent cardiac arrest of hypoxia etiology. For pediatric patients, management of different life-threatening arrhythmias, PEA arrest/asystole, or VF/VT arrest is similar to adults except the dosage (defibrillation/medication) for children is weight-based. Actual body weight is recommended to calculate initial resuscitation drug doses. The 2015 AHA Guidelines for CPR and ECC on pediatric ACLS for bradycardia, tachycardia, and pulseless arrest are illustrated in Figs. 86.11–86.13.⁹¹



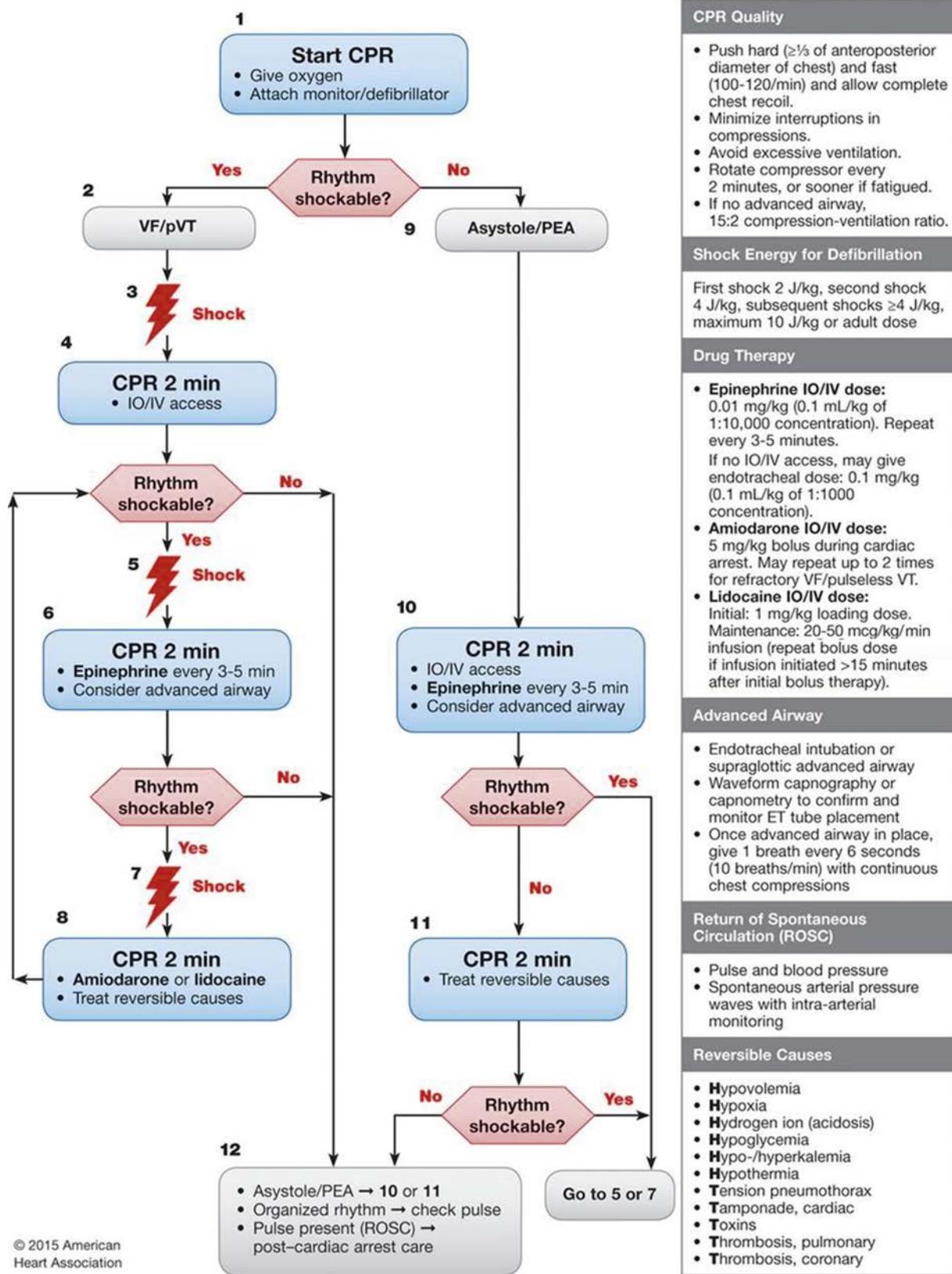
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Fig. 86.12 2015 American Heart Association Pediatric Tachycardia With a Pulse and Poor Perfusion Algorithm. *IO*, Intraosseous; *IV*, intravenous. (From de Caen AR, Berg MD, Chameides L, et al. Part 12: Pediatric Advanced Life Support: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S526–542.)

For bradycardia, continue to support airway, ventilation, oxygenation, and chest compressions. Emergency TCP may be lifesaving if the bradycardia is due to complete heart block or sinus node dysfunction unresponsive to the aforementioned measurements and medications, especially if it is associated with congenital or acquired heart disease. For SVT, attempt vagal stimulation first, unless the patient is hemodynamically unstable or the procedure will delay chemical or electric cardioversion. An IV/IO dose of adenosine 0.1 mg/kg rapid bolus is used first; if it fails, then a second dose of 0.2 mg/kg rapid bolus is given, the maximum second dose is 12 mg. Verapamil, 0.1 to 0.3 mg/kg, is also effective in terminating SVT in older children, but it should not be used in infants without expert consultation because it may cause potential myocardial depression, hypotension, and cardiac arrest. When cardioversion is indicated in unstable SVT, start with a dose of 0.5 to 1 J/kg.

If unsuccessful, increase the dose to 2 J/kg. For a patient with SVT unresponsive to vagal maneuvers and adenosine and/or electric cardioversion, consider amiodarone 5 mg/kg IO/IV or procainamide 15 mg/kg IO/IV; for hemodynamically stable patients, expert consultation is strongly recommended prior to administration. For wide-complex (> 0.09 second) tachycardia, consider electric cardioversion after sedation using a starting energy dose of 0.5 to 1 J/kg. If that fails, increase the dose to 2 J/kg.

Regarding resuscitation medication, it is reasonable to administer epinephrine in pediatric cardiac arrest. For shock-refractory VF or persistent VT, either amiodarone or lidocaine may be used. Calcium administration is not recommended for pediatric cardiopulmonary arrest in the absence of documented hypocalcemia, calcium channel blocker overdose, hypermagnesemia, or hyperkalemia. Routine administration of sodium bicarbonate is not



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Fig. 86.13 2015 American Heart Association Pediatric Cardiac Arrest Algorithm. *CPR*, Cardiopulmonary resuscitation; *IO*, intraosseous; *IV*, intravenous; *PEA*, pulseless electric activity; *VF*, ventricular fibrillation; *VT*, ventricular tachycardia. (From de Caen AR, Berg MD, Chameides L, et al. Part 12: Pediatric Advanced Life Support: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015;132[18 suppl 2]:S526-S542.)

recommended in cardiac arrest. A dose of 0.02 mg/kg of atropine may be considered before emergency intubation.

Observational data from a registry of pediatric IHCA showed improved survival to hospital discharge with the use of ECMO cardiopulmonary resuscitation (ECPR) in patients with surgical cardiac diagnoses.⁹² For children with underlying cardiac disease, when ECPR is initiated in a critical care setting, long-term survival has been reported even after more than 50 minutes of conventional CPR.⁹³ When ECPR is used during cardiac arrest, the outcome for children with underlying cardiac disease is better than for those with noncardiac disease.⁹⁴ Therefore, ECPR may be considered for pediatric patients with cardiac diagnoses who have IHCA in settings with existing extracorporeal membrane oxygenation (ECMO) protocols, expertise, and equipment.

For infants and children remaining comatose after OHCA, it is reasonable either to maintain 5 days of continuous normothermia (36°C–37.5°C) or to maintain 2 days of initial continuous hypothermia (32°C–34°C), followed by 3 days of continuous normothermia. Fever (temperature 38°C or higher) should be aggressively treated with antipyretics and cooling devices after ROSC.

Myocardial dysfunction and vascular instability are common after resuscitation from cardiac arrest.⁹⁵ After ROSC, IV fluids and/or inotropes or vasoactive drugs are recommended to maintain a systolic blood pressure greater than fifth percentile for age. When appropriate resources are available, continuous arterial pressure monitoring is recommended to identify and treat hypotension.

HIGHLIGHTING THE SIMILARITIES OR DIFFERENCES VERSUS ADULT RESUSCITATION

The similarities and differences of pediatric and adult BLS are listed in Table 86.1 and discussed in the Basic Life Support section. The asphyxial nature of the majority of pediatric cardiac arrests necessitates effective ventilation as part of the CPR. Conventional CPR (rescue breathing and chest compressions) should be provided for pediatric cardiac arrests. For infants, a manual defibrillator is preferred when a shockable rhythm is identified by a trained healthcare provider. An AED with a pediatric attenuator is also preferred for children less than 8 years of age. If neither is available, an AED without a dose attenuator may be used. As previously described, the defibrillation energy dose and resuscitation medication doses are all weight based.

FOREIGN BODY AIRWAY OBSTRUCTION

Although recognition and management has improved, foreign body aspiration (FBA) remains common in children. FBA can occur in children of all ages, although most occur in children younger than 4 years of age, with a peak incidence between the first and second years of age.⁹⁶ Liquids are the most common source for infant choking while small objects (e.g., balloons, food) are responsible for most childhood choking.⁹⁷ Clinical symptoms and signs vary based on the location of the foreign body and the degree of obstruction. The clinical presentation may also change over time as a result of movement of the foreign body within the respiratory tract.

If a child is making sounds or coughing, the adult should carefully monitor but not intervene. If the child is choking, abdominal thrusts (the Heimlich maneuver) or back blows should be performed until the obstruction is relieved. In either circumstance, if the choking infant or child becomes unresponsive, CPR should be started with 30 chest compressions, followed by an airway examination to identify the presence of the foreign body. Two rescue breaths should be attempted. If the airway obstruction is not relieved, then CPR should be restarted and continued until the airway obstruction is relieved. If a foreign body is visible above the vocal cords during laryngoscopy, an attempt should be made to extract it with Magill forceps. If the foreign body is below the vocal cords, it is reasonable to attempt to push the foreign body more distally to reestablish a patent airway. This may allow for rescue oxygenation and ventilation while preparing for more definitive management.

DROWNING

Drowning is an important cause of OHCA in children and results in approximately 1100 pediatric deaths in the United States annually.⁹⁸ It remains one of the leading causes of death in children and adolescents worldwide. The most important positive prognostic indicators include shorter submersion time, salt versus freshwater submersion, and time from rescue to receiving CPR.^{99,100} Thus prehospital care is paramount to improve patient outcome.

When a drowning infant or child is encountered by a single rescuer, a CPR pattern of 2 minutes of 30:2 compression-to-ventilation should be provided before summoning help. If two or more rescuers are available, then help should be immediately summoned. Oxygen and ventilation should be provided at the earliest opportunity because respiratory arrest is usually the primary etiology. Heimlich maneuver is not beneficial in the case of drowned patients because it potentially increases time to intubation and the possibility of gastric aspiration.¹⁰¹ Cuffed ETTs are preferred due to decreased lung compliance secondary to submersion-induced lung injury. The outcomes of survivors of cardiac arrest secondary to drowning are usually better compared with other respiratory etiologies.¹⁰² However, it is very difficult to predict prognosis from initial presentation, with many of the most unexpected physiologic recoveries occurring in the young; therefore, aggressive resuscitation of a patient following submersion should always be undertaken until either ROSC or arrival at the emergency department, at which point further efforts such as ECMO may be considered.

SUDDEN UNEXPLAINED DEATHS

Unexpected and unexplained deaths in infants and children can result from cardiac and noncardiac etiology. Cardiac etiology is often attributed to cardiac arrhythmia caused by cardiac ion-channel dysfunction secondary to genetic variations or mutations, which may be undetectable in a conventional autopsy. In 2% to 10% of infants or children and 14% to 20% of young adults who experience sudden cardiac death, channelopathies are found on autopsy.^{103,104} First- and second-degree relatives of young children who unexpectedly die should undergo a genetic

analysis to detect undiagnosed channelopathies. Noncardiac conditions include epilepsy, upper airway obstruction from infectious/noninfectious reasons resulting in respiratory arrest, febrile seizures, infection, metabolic disorders, and hippocampal pathology.¹⁰⁵

TERMINATION OF PEDIATRIC RESUSCITATION ATTEMPTS

Accurate and reliable prognostication during pediatric cardiac arrest would allow termination of CPR when it is futile, while encouraging continued CPR in patients with a potential for good recovery. Several post-ROSC factors have been studied as possible predictors of survival and neurologic outcome after pediatric cardiac arrest. These include the presence of hypotension, serum neurologic biomarkers, and serum lactate. Although these factors are associated with better or worse outcomes, no single factor predicts outcome with sufficient accuracy to recommend termination or continuation of CPR. The AHA 2015 Guidelines for CPR and ECC on pediatric ACLS recommend that multiple variables are used when attempting to prognosticate outcomes during cardiac arrest.

Observational data from two small pediatric studies showed that a continuous and reactive tracing on an EEG performed in the first 7 days after cardiac arrest is associated with a significantly higher likelihood of good neurologic outcome at hospital discharge. In contrast, an EEG demonstrating a discontinuous or isoelectric tracing is associated with a poor neurologic outcome at hospital discharge.^{106,107} Thus EEG within the first 7 days after pediatric cardiac arrest may be considered in prognosticating neurologic outcome at the time of hospital discharge, although it should obviously never be used as the sole criterion.

Prolonged resuscitations might be considered for infants and children with recurring or refractory VF or VT, particularly if cardiopulmonary support with ECMO is available and the source for the cardiac arrest is believed reversible.¹⁰⁸

Future of Resuscitation Science and Care

INDIVIDUALIZED CARDIOPULMONARY RESUSCITATION

As described earlier in this chapter, survival and neurologic outcome in victims of cardiac arrest are critically dependent on the duration of the “no-flow” arrest (circulatory arrest with no chest compressions), as well as the quality of chest compressions during the “low-flow” phase of CPR. Therefore, it is important to provide early and high-quality chest compressions and to use every measure to facilitate early ROSC, irrespective of the cause of the arrest. Recent data have, nevertheless, shown that in addition to this general approach, interventions aimed at specific conditions or physiologic parameters can also affect the chance of ROSC and survival. This individualized approach to CPR has become increasingly important given the persistent poor outcome after cardiac arrest despite efforts to improve implementation of current guidelines, AED accessibility, and provider training.

The use of ECG filtering techniques and fibrillation analysis algorithms has been investigated to identify the optimal time for successful defibrillation from VF. A problem coherent to this technique has been the need to stop chest compressions for rhythm analysis, which is proven to adversely affect the effectiveness of the subsequent chest compressions. The recent development of the “See-Through” technology to extract CPR artifacts from the ECG is promising, as it allows continued chest compressions during ECG analysis but has been criticized for a relatively low specificity that prohibits its incorporation into the AED diagnostic algorithm.¹⁰⁹ Amplitude spectral area (AMSA) is an index for analyzing ventricular fibrillation waveforms to predict ROSC after defibrillation. Nakagawa and associates showed that change in AMSA (Δ AMSA) before the electric shock reliably predicted ROSC in 285 VF patients.¹¹⁰ Segal and associates report a moderate positive correlation between ETCO₂ and AMSA during CPR in pigs.¹¹¹

As was described in the 2015 AHA Guidelines for CPR and ECC ACLS update, provider performance feedback during CPR can also help optimize CPR quality. Despite the absence of convincing evidence, it is reasonable to use quantitative waveform capnography, arterial pressure monitoring, and central venous oxygen saturation when feasible to monitor and optimize CPR quality and guide vasopressor therapy. Gonzalez-Otero and associates recently reported that an accelerometer-based real-time feedback system to guide rescuers during CPR can improve adherence to published resuscitation guidelines. Spectral analysis of chest acceleration was used to compute the depth and rate of chest compressions.¹¹² The use of a novel CPR card feedback device was also shown to improve the quality of chest compressions.¹¹³

In addition to interventions aimed at improving the quality of chest compressions, recent data suggest that optimization of oxygen delivery to the ischemic tissue can also be complemented by enhanced ventilation strategies. Chest Compression Synchronized Ventilation (CCSV) is designed to detect starting chest compression efforts and to initiate an instant inspiratory pressure through reprogramming of the Pressure Support Ventilation mode. It comprises an inverse trigger, cycling mechanisms, and higher inspiratory pressure levels up to 60 mbar. Kill and colleagues showed that when compared with Intermittent Positive Pressure Ventilation (IPPV), CCSV results in a higher PaO₂ without an arterial blood pressure drop during resuscitation in pigs.¹¹⁴ The same group of investigators reported that CCSV is associated with better delivery of the respiratory parameters and minimizes excessive inspiratory pressures that can potentially lead to pulmonary injury during simulated CPR.¹¹⁵

Extracorporeal Membrane Oxygenation

ECMO with CPR (ECPR) continues to evolve as a therapeutic option for refractory cardiac arrest.¹¹⁶ Its use has significantly increased over the last few years, and new techniques are being developed to enhance its feasibility and access.¹¹⁷ In a meta-analysis of 10 recent publications, Kim and associates reported a trend toward improved short-term (3-6 months) survival and neurologic outcome with ECPR as compared with conventional CPR.¹¹⁸ Debaty and associates reported that shorter low-flow duration, shockable cardiac rhythm, higher arterial pH value, and lower serum lactate

concentration on hospital admission are associated with better outcomes for ECPR recipients after OHCA.¹¹⁹ Dennis and associates confirmed that in selected patients with refractory cardiac arrest, ECPR may provide temporary support as a bridge to intervention or recovery. Favorable survival and neurologic outcomes were reported in one-third of patients with pre-ECMO lactate levels predictive of mortality.¹²⁰

Controlled Automated Reperfusion of the whole body (CARL) is a new type of extracorporeal circulation device that provides continuous adjustments of reperfusion conditions with the recirculating blood according to the individual readings of each patient. It combines measures to control arterial blood pressure and blood flow with TTM, as well as control of the acid-base status, oxygen content, osmolarity, and electrolytes to minimize the ischemia-reperfusion injuries. Based on data from experimental studies, recently Trummer and associates successfully employed CARL after 120 minutes of normothermic CPR in a patient. Except for a spinal cord injury resulting in lower extremity weakness, the patient was reported to have survived without any neurologic deficits.¹²¹

Emergency preservation for delayed resuscitation (EPR) or suspended animation is another promising approach to enable intact survival in patients who are expected to fail conventional resuscitation techniques. It was developed by the Safar team at the University of Pittsburgh to apply profound hypothermia to preserve the organism and avoid irreversible organ damage and buy enough time to obtain surgical hemostasis in victims of exsanguination cardiac arrest. This concept has been tested successfully in multiple large animal studies, confirming that full recovery is possible for up to 2 hours of no-flow cardiac arrest when profound hypothermia to 10°C is induced within minutes, and is then followed by delayed resuscitation using cardiopulmonary bypass or extracorporeal circulation. Tisherman and associates recently reported the development of the first multicenter clinical trial of EPR in victims of traumatic cardiac arrest.¹²² If successful, EPR can also be employed as an alternative resuscitation approach in patients with refractory intraoperative exsanguination cardiac arrest.

COORDINATED POSTRESUSCITATION CARE

Postresuscitation syndrome is a complex pathophysiologic condition first described by Negovski and associates in the 1970s, and can significantly affect the outcome after cardiac arrest.¹²³ It is characterized by myocardial dysfunction, neurologic injury, and systemic perturbations associated with the reperfusion of the ischemic tissue. Post-cardiac arrest care must therefore incorporate measures to minimize the systemic ischemic-reperfusion response, improve myocardial function, and prevent postresuscitation brain injury and other systemic complications. It is recommended that survivors of cardiac arrest are admitted to specialized centers for early goal-directed therapy, including optimization of the hemodynamics and respiratory parameters, urgent coronary angiography, and TTM. It is important to note that TTM is considered in all comatose survivors of cardiac arrest, whose temperature should be monitored closely (goal between 32°C and 36°C) for at least 24 hours. It is also recommended to continue monitoring the temperature and maintain normothermia (treat fever) beyond this

window. Prognostication should not occur until 72 hours after ROSC or, if TTM is provided, 72 hours after completion of TTM. A useful tool to predict outcome after cardiac arrest is the GO-FAR score, which was derived from the Get With the Guidelines-Resuscitation registry and identifies a large proportion of patients (28.3%) who have a low or very low likelihood (<2%) of achieving good outcome.¹²⁴ Seizure control is also important, but neuroprotective agents such as thiopental, magnesium, and calcium channel inhibitors are not routinely administered and have not been shown to improve outcomes. With the evolution of ECPR, nevertheless, there has been a resurgence of studies aimed at identifying effective neuroprotective agents. Examples include adenosine 2A receptor (A2AR) agonists, which have been suggested to attenuate the ischemia-reperfusion injury during ECPR.¹²⁵ A2AR activation can reduce proinflammatory mediators, endothelial adhesion molecule expression, and transmigration of circulating inflammatory cells into tissue through inhibition of lymphocytes, macrophages, monocytes, platelets, and neutrophils. Inhaled nitric oxide (iNO) is also an emerging approach to the treatment of the post-cardiac arrest syndrome and to reducing the ischemia-reperfusion injury. In a pig model of cardiac arrest precipitated by lipopolysaccharide-induced hypotension, Morgan and associates showed that pulmonary vasodilation with iNO improved short-term survival and intra-arrest hemodynamics.¹²⁶ Human studies are forthcoming, but there are currently insufficient data to recommend routine use of any of these novel therapies.

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EDWARD A. BITTNER, J.A. JEEVENDRA MARTYN, and FOLKE SJÖBERG

KEY POINTS

- Major burn injury results in pathophysiologic changes affecting virtually all organs from the onset of injury until wounds are healed. Anesthesiologists are often called on to care for burn injury patients through their hospitalization including acute airway management and resuscitation, intraoperative anesthetic care, intensive care, and management of postoperative pain.
- Burn shock is a paradigm of ischemia/reperfusion injury. The initial ischemic (ebb) phase of burn shock is a hypodynamic, hypovolemic state, with rapid loss of fluid from the intravascular space and decreased cardiac output, which typically lasts for the first 24 to 48 hours following injury. Approximately 48 hours after successful resuscitation, a hyperdynamic, hypermetabolic (flow) phase ensues consisting of tachycardia, increased cardiac output, hyperthermia, hyperglycemia, and increased protein catabolism.
- The goal of fluid resuscitation is to maintain organ perfusion by replenishing the massive loss of fluid from intravascular to extravascular compartments. Multiple fluid resuscitation formulae exist for estimating fluid needs and differ somewhat in their recommendations for the amount of crystalloid and colloid replacement. No matter which formula is used, it should serve only as a guideline, and fluid resuscitation should be titrated to physiologic endpoints.
- Inhalation injury is a major prognostic factor for morbidity and mortality after burn injury. Management of inhalation includes observation and monitoring. Endotracheal intubation or tracheostomy is indicated if airway patency is threatened.
- Patients with severe burn injury often suffer from nonthermal traumatic injuries. Failure to diagnose these associated injuries during initial evaluation can lead to serious morbidity and mortality. All burn patients should be approached initially as multiple-trauma patients.
- The magnitude of burns is classified according to percentage of total body surface area (TBSA) involved, depth of the burn, and the presence or absence of inhalational injury. Accurate estimation of burn magnitude is needed to guide the initial resuscitation strategy, make the referral to a burn center, ascertain the need for surgery, and to estimate prognosis. Three of the most commonly used methods to estimate %TBSA are the “rule of nines,” palmar surface area, and the Lund-Browder diagram.
- “Fluid creep” refers to the trend of over-resuscitation in burn injury patients. Overly aggressive fluid administration may result in pulmonary edema, compartment syndromes, multiorgan failure, nosocomial infection, and increased mortality as well as the extension of the burn injury because of excessive local edema. Factors that contribute to “fluid creep” include overestimation of the burn size, use of supra-physiologic hemodynamic targets, increased opioid utilization, and failure to reduce the rate of fluid administration in patients with evidence of adequate tissue perfusion.
- Electrical burns can have acute and chronic effects not occurring with other types of burn injury, and with morbidity far higher than expected based on burn size estimation alone. High-voltage injuries are typically associated with loss of consciousness, arrhythmias, myoglobinuria, and extensive deep tissue damage that can result in compartment syndromes. Patients suffering from electrical injury should be evaluated for associated traumatic injury, rhabdomyolysis, and compartment syndromes. For treatment of these complications, patients may come to the operating room within 24 hours of injury.
- Airway management in the burn-injury patient may be challenging and warrants particular consideration. Key features of airway assessment include preexisting airway abnormality, current airway injury (i.e., inhalation injury), and signs of glottic obstruction. The type of airway abnormalities may vary depending on the stage of the injury. In the acute burn setting, mandibular mobility and mouth opening may be limited because of edema or, in later care, may have significant scarring and contractures in the face, mouth, nares, neck, and chest which can make airway management difficult.
- Burn-injured patients develop tolerance to most narcotics and sedatives, thereby requiring substantially higher doses than patients without thermal injury. Sedatives and narcotics should be titrated to effect while the patient is carefully monitored. Adverse effects of opioids, such as respiratory depression, acute opioid tolerance, and hyperalgesia, particularly with the need for rapidly escalating doses, have generated increasing attention to multimodal strategies.

- Muscle relaxant pharmacology is significantly and consistently altered after burn injury. Exposure to succinylcholine can result in an exaggerated hyperkalemic response, which can induce cardiac arrest. The current recommendation is to avoid succinylcholine administration in patients 48 to 72 hours after burn injury. The duration of this dangerous response to succinylcholine after burn injury is unknown.
- Surgical excision of burn wounds is often associated with substantial bleeding. It is not uncommon for the surgical team to remove eschar so rapidly that the patient becomes hypovolemic and hypotensive. Clinical judgment remains a vital component for intraoperative resuscitation, using markers of perfusion, erythrocyte mass, and coagulation, pulse, or arterial waveform as key assessment tools. Good communication between the surgical and anesthesia teams as well as limiting the operative duration and extent of excision are also essential.
- Patients with major burn injury have an impaired ability for thermoregulation and therefore require close monitoring of body temperature. Multiple strategies are used to maintain body temperature in the operating room, including use of forced-air warming blankets, thermal water mattresses, blood/fluid warmers, minimizing skin surface exposure, and wrapping the head and extremities with plastic or thermal insulation.
- Postoperatively, burn-injured patients are likely to be less stable physiologically compared with the preoperative period. Continued bleeding may be concealed by dressings, the patient may be more prone to hypothermia, emergence may be associated with delirium, and analgesic requirements will be greater. During this period of exaggerated physiologic fragility, it is important to be especially vigilant during transfer of the monitors and respiratory and hemodynamic support equipment to the intensive care unit staff.
- Burn injury leads to increased susceptibility to infection due to decreased immunity through multiple mechanisms including loss of the physical barrier of intact skin, damage to lining of the respiratory tract from inhalation injury, and altered gut permeability and function. Preventative measures against infection are critical for the burn-injury patient and include early excision of burn eschar to improve local perfusion and prevent microbial colonization, prudent use of invasive devices, application of antimicrobial burn dressings, and diligent compliance with infection control.
- Nearly all aspects of burn care (e.g., dressing changes, excision and grafting procedures, physical therapy, and line insertion) are associated with pain. There can be ongoing background pain, periodic breakthrough pain, procedure-related pain, and eventually, chronic pain can develop. Standardized pain and anxiety guidelines are used to provide appropriate, consistent patient comfort.

Introduction

Burn injuries are among the leading causes of injury and death worldwide, with about 11 million seeking medical care and over 265,000 deaths annually. Over 95% of these occur in low- and middle-income countries.¹ Approximately 486,000 burn injuries are treated at U.S. medical facilities each year of which 40,000 require hospital admission with approximately 3275 deaths.²

Major burn injury produces pathophysiologic changes that affect virtually all organs from the very onset of injury until after the wounds heal. Pathophysiologic effects may persist for years especially in patients with major injuries and include insulin resistance, neuromuscular dysfunction, pruritus, pain, and more frequent hospital admissions related to infections and cardiomyopathies.³⁻⁵ Severe burn injury patients are different from other intensive care patients as they pose challenges regarding fluid resuscitation, metabolic stress, perioperative demands, and other specific burn injury-related complications. Most burn injury patients present to emergency rooms in community hospitals, which do not have a designated burn center. After initial acute care, these patients are usually transferred to tertiary care facilities with a specialized burn center. As a result, anesthesiologists staffing these peripheral hospitals with

emergency rooms must be familiar with the pathophysiology of acute burn injury and resuscitation. In addition, treatment of a burn injury patient requires multiple operations, frequent dressing changes, and prolonged hospital stay with extensive rehabilitation needs. In burn care facilities, anesthesiologists need to have expertise in the specific management of the pathophysiologic changes affecting these victims and particularly the unique features of perioperative management of this patient population. Therefore there is a continuous need for specific teaching, training, and maintenance of specialized skills in this field.⁶

Although morbidity from burn-related injuries remains high, advanced methods of resuscitation, early excision and grafting of burn wounds, better methods of wound coverage, improved anesthesia and intensive care techniques, early diagnosis and aggressive treatment of infections, as well as enhanced nutritional support and mental health-care methods have led to significant decrease in burn injury-related morbidity and mortality. Other factors, including immediate prehospital care, early emergency treatment with advanced life support capability, and secondary transfer to a specialized burn unit have also contributed to improved survival.⁷ Despite significant advances in therapeutic strategies, care of the burn injury patient continues to pose multiple challenges for clinicians.

Pathophysiology

BURN SHOCK

Burn injury can cause massive tissue destruction and result in activation of an inflammatory response that leads to profound pathophysiologic effects at sites both local and distant from the injury. Understanding the pathophysiologic alterations and their time course is essential for providing appropriate resuscitation and perioperative care.

Burn shock is a paradigm of ischemia/reperfusion injury.⁸ The initial ischemic (ebb) phase of burn shock is a hypodynamic, hypovolemic state, with rapid loss of fluid from the intravascular space and decreased cardiac output, which typically lasts for the first 24 to 48 hours following injury. A large volume fluid resuscitation is required to maintain intravascular volume for organ reperfusion, acutely diluting plasma proteins. Approximately 48 hours after successful resuscitation, a hyperdynamic, hypermetabolic (flow) phase ensues due to the systemic inflammatory responses from the trauma-induced release of damage-associated molecular patterns (DAMPS), even in the absence of overt infection.⁹ This is characterized by increased cardiac output, oxygen consumption, muscle protein catabolism, and body temperature, lasting for many months to years after healing of the burn wounds. When burn shock is left untreated, physiologic exhaustion ensues and is fatal.

The goal of fluid resuscitation is to maintain organ perfusion by replenishing the massive loss of fluid from intravascular to extravascular compartments. There are two main reasons for this loss, both of which have been extensively investigated and have clear temporal patterns. First, there is the negative imbibition pressure in tissues injured by a burn¹⁰⁻¹³ and, second, there is an increase in vascular permeability with loss of fluid from the vasculature as well as from the injured areas.¹⁴ In the injured areas, there is protein loss from the vasculature in addition to crystalloid loss. At the uninjured distant sites, there is capillary sieving of protein with loss of crystalloid only.¹⁵

NEGATIVE IMBIBITION PRESSURE

When fluid losses were investigated in experimental models they could not be explained completely by an increase of permeability, and it was then postulated that there must be another mechanism that would explain these losses. In 1960, Gösta Arturson suggested that the loss from the blood could be explained by a reduction in the interstitial tissue pressure.¹⁶ Subsequently, Lund et al. using *in vitro* models showed that there is a build-up of strong negative interstitial pressure within injured tissue causing a negative interstitial pressure in the range of -25 to -50 mm Hg (Fig. 87.1).¹⁷ This negative gradient, called negative imbibition pressure, explains most of the early total fluid loss. Imbibition pressure is a negative pressure where water or crystalloid is absorbed causing large increases in volume and is different from hydrostatic and osmotic pressure. More recent *in vivo* studies by Kinsky and associates have confirmed the previous *in vitro* findings on imbibition pressure.¹⁸ This negative imbibition pressure is most pronounced immediately after the burn and remains for several hours. Intriguingly, the fluids provided during resuscitation seem to have an adverse effect on the negative imbibition

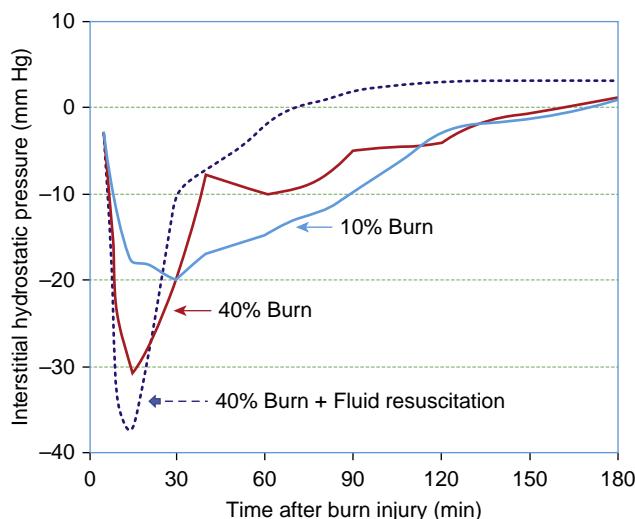


Fig. 87.1 Negative imbibition pressure. Graph showing how negative interstitial fluid pressure changes over time and varies based on the size of the burn injury and the administration of fluid.

pressure (see Fig. 87.1). Administering a greater amount of fluid results in larger negative tissue imbibition pressure, and correspondingly larger fluid leak and overall demand for fluids. The mechanism underlying the development of negative tissue pressure is not well understood, but probably results from the effect of thermal energy on the tissue integrins (components important for the regulation of hydrostatic pressure in the interstitium), which lose the ability to maintain their beneficial effect on imbibition pressure. The magnitude of the burn seems to affect this defect; the larger the burn injury, the more pronounced is the negative pressure in the tissue.¹³ This is the reason for early hypovolemia despite fluid treatment therapy. Importantly, most of the intravascular fluid loss disappears within 24 to 48 hours.²⁰ The resorption of the extravascular edema fluid, however, takes much longer as detailed later in the *Fluid Resuscitation Strategies* section.

PERMEABILITY EFFECTS OF THE BURN

The loss of fluid from the intravascular space is also due to the increase in vascular permeability. This effect is obvious even in a small 5% total body surface area (TBSA) burn and occurs soon after the injury, explaining the blister formation even with small burn injury. Detailed mechanisms as to how even a small burn causes leakage of fluid is unclear, but there seem to be a number of putative mediators (see also section on *Mediators Important in Fluid Loss*). Another important aspect of vascular permeability is the onset of vasodilatation in most vascular beds as a result of the continued liberation of proinflammatory cytokines into the injured tissues. This vasodilatation increases the hydrostatic pressure in the microcirculation, which leads to further loss of fluid into the interstitial compartment. The Starling equation given here further describes the different factors that play a role in fluid filtration:²⁰

$$J_v = K_f ((P_c - P_i) - \sigma (\pi_c - \pi_i))$$

where J_v is the fluid volume, K_f the filtration coefficient, P_c the capillary hydrostatic pressure, P_i the interstitial hydrostatic pressure, σ the reflection coefficient, π_c is the capillary

osmotic pressure, and π_i the interstitial osmotic pressure. In particular, the coefficient of filtration increases dramatically, often to a range 20-fold greater; for the latter parts of the formula, there is an increase in hydrostatic pressure in the capillaries due to vasodilatation; decrease in interstitial pressure (the negative imbibition pressure) together with a decrease in colloid osmotic pressure within the capillaries as the result of a capillary leak, onto which also the increased osmotic effect of proteins lost into the interstitium, is added.

Although these changes affect most vascular compartments, the effect at the venular-end seems more important from a quantitative perspective. Most of the proteins lost across the vascular wall are smaller molecules; a few larger proteins are also lost. This large protein loss is important to note, as it underlies the arguments in favor of so-called “colloid rescue” fluid resuscitation in larger burns, which reduces the total colloid loss (and corresponding total fluid loss) with decreased risk of compartment syndromes.²² It is important to stress that the loss of fluid from the intravascular space is due to alterations in **all** the factors previously described, which are important for the transport of fluid across the capillary and venular walls, and therefore contribute to the large fluid volume loss after burn injury.

In clinical practice, the increase in permeability, dilution effects of the resuscitation, and loss of protein manifest as a decrease in the concentration of serum albumin. The intravascular colloid osmotic pressure during the acute phase of burn injury is dependent not only on albumin but also on the newly synthesized acute phase proteins. Uncertainties in the temporal pattern of the vascular leak of protein locally means that the optimal timing of colloid administration is unclear. Thus the intense debate as to when colloids can safely be started during fluid resuscitation continues. Today most burn clinicians would agree that it is appropriate to start colloids 8 to 12 hours postburn to reduce the total fluid volume (see section *Colloid Rescue Treatment*). It is important to understand, however, that early colloid administration may lead to its extravasation into the extravascular space with a concomitant increase in tissue edema. It must also be noted that even in the absence of burn injury only 20% of the administered crystalloid fluid volume stays within the vasculature, and that large volumes of crystalloid alone will decrease intravascular colloid osmotic pressure and cause a further loss of fluid from this compartment.²³ These interrelated effects must be appreciated when fluid resuscitation for a burn injury patient is initiated. However, the previous dictum that the first 24 hours after burn should consist of only crystalloids does not hold anymore.

FLUID LOSS IN BURNS: THE TEMPORAL ASPECT

When caring for burn injury patients, it is important to discuss the temporal aspects of the fluid loss, and the recommended fluid management. This is particularly important, as recent investigations have shown that in present guidelines there is a clear temporal mismatch between fluid loss and fluid volume protocols. Most of the fluid that is lost from negative imbibition pressure is lost within the first 3 to 4 hours after the burn. The picture is somewhat different for the fluid that is lost from the increase in permeability. The most reliable data in humans has suggested that this fluid is lost at the time of the injury, and up to 8 to 10 hours

later.^{24,25} The permeability effects continue even after 48 hours due to the continuous systemic inflammatory response that is ongoing after the burn, although its magnitude is significantly less, unless complicated by sepsis.

More important is that the present guidelines for fluid resuscitation, particularly if they are based purely on crystalloids, do not fully account for this early loss of fluid. The patient may therefore be claimed to be in a controlled hypovolemic state during the first 12 to 16 hours after the burn injury. The tissue edema reaches its maximum between the first 24 to 48 hours after the injury, and thereafter the added fluid volume is slowly returned to the circulation and excreted as urine, often until 7 to 14 days after the burn depending on the magnitude of the injury.²⁶ This is also the time when lung dysfunction can occur because of hypervolemia from the reabsorbed fluid.

Mediators Important in Fluid Loss

Many mediators have been thought to be important in the underlying mechanisms of fluid loss in burns, and there are probably several that contribute in different ways. The most important are: serotonin, nitric oxide, thromboxanes, prostaglandins, and several others including reactive oxygen species and proinflammatory cytokines.²⁷ But molecular mediators are not the only substances implicated in the permeability effects; white blood cell-related effects have also been suggested.^{28,29} Coagulation and the complement cascade are thought to be activated early, and also play an important part. Interest in the mediators and their possible role in the generation of fluid losses is driven by the hope of finding a treatment that can stop or reduce the process. Some attempts have been made and the most successful has been the use of high-dose vitamin C (as a scavenger of oxygen radicals) which, in randomized trials in both animals and humans, showed a reduction in fluid loss in the treatment arm.^{30,31} In addition, direct effects were seen on the negative imbibition pressure with vitamin C administration.³²

Hemodynamic Alterations

Burn shock can result in profound hemodynamic alterations associated with organ dysfunction. Severe burn shock is both distributive and hypovolemic in nature. The increased systemic vascular resistance (SVR) (due to release of catecholamines, antidiuretic hormone, and hemoconcentration) compounds the shock phase adverse effects.

A reduction in cardiac output also often occurs with major thermal injury even before any detectable reduction in plasma volume and may continue even when hypovolemia is alleviated.³³ The cardiac dysfunction is characterized by slowed isovolemic relaxation, impaired contractility, and decreased left ventricular diastolic compliance and often continues for 24 to 36 hours.^{34,35} Burn-related left ventricular contraction and relaxation defects increase with burn size, achieving a nadir with 40% TBSA burns.³⁶ This cardiac dysfunction has been identified as a major cause of multiple organ dysfunction syndrome (MODS) and mortality.

A hyperkinetic and hypermetabolic state develops 48 to 72 hours after burn injury, and is characterized by a decrease in vascular permeability, increased heart rate, and decreased SVR resulting in an increase in cardiac output.

Cardiac output is often increased to more than 1.5 times that of a nonburned, healthy patient 3 to 4 days following the injury. The metabolic rate is increased, approximately 1.5 times that of normal basal rate.³⁷ This increase in cardiac output is associated with increased liver and kidney blood flow, which has implications for elimination of blood flow-dependent drugs including some antibiotics and anesthetic drugs. The onset of sepsis may further increase cardiac output and decrease SVR.

Inhalation Injury

PATHOPHYSIOLOGY

In addition to age and the extent of burns, inhalation injury is a major prognostic factor for morbidity and mortality after burn injury. Inhalation injury can be classified under three subcategories: direct thermal injury to the upper airway; chemical irritation to the lower (subglottic) airway and even lung alveoli; and systemic chemical or metabolic injury caused by specific noxious combustion chemicals, or a combination of these factors.³⁸ Direct heat and steam injury to the upper airway can lead to marked swelling of the face, tongue, epiglottis, and the glottic opening resulting in an upper airway obstruction. Because airway swelling may not occur immediately but may develop over a period of hours (especially with, and complicated by, concurrent fluid resuscitation), a high index of suspicion and frequent reevaluations of the respiratory status are essential. A scald injury of the epiglottis may mimic symptoms of epiglottitis.³⁹

Thermal injury to the lower airway is uncommon due to a highly efficient heat exchange system in the oropharynx and nasopharynx and the low specific heat of steam in conjunction with the laryngeal closure reflex due to the irritation. Damage to the lower airways and lung parenchyma following smoke inhalation tends to be chemical rather than thermal. Toxic substances in smoke damage the epithelium and capillary endothelial cells of the airway resulting in the release of inflammatory mediators, increased vascular permeability, and edema of distal bronchi and alveoli. Many of the previously listed mediators are relevant here as well. Damaged mucosal cells produce excess exudates rich in protein and necrotic debris. Chemicals in smoke promote the formation of neutrophil-generated oxygen radicals leading to inflammation. Destruction and damage to the airway's ciliary transport function leads to the accumulation of casts, airway plugging, and impaired clearance of bacteria and debris.⁴⁰ Alveolar collapse and atelectasis can occur because of loss of surfactant production or from plugging of small airways by mucosal debris. Over time, these changes can result in bronchospasm, airway obstruction, atelectasis, and pneumonia, which cause ventilation perfusion mismatch, impaired gas exchange, and decreased pulmonary compliance. The severity of inhalation injury may not be directly proportional to the degree of exposure to smoke alone. Rather, the severity of injury is probably due to the composition of the inhaled material and combustion substances together with differences in the individual host response as well as added effects from the cutaneous burn.

Injury to the airways and lung can also occur with severe cutaneous burns in the absence of inhalational injury.

Mechanisms include the effects of inflammatory mediators from the burn-injured area, and the effects of fluid resuscitation and infection. For example, acute lung injury can occur in patients with scald injury without smoke exposure where bronchoscopic features can mimic smoke-induced airway injury.^{41,42}

While the gas-phase components of smoke do not produce direct injury to the respiratory tract, they can produce systemic effects. Among the most toxic gas-phase components are carbon monoxide (CO) and cyanide inhalation, which can lead to major morbidity and mortality following inhalation injury. CO is an odorless, colorless gas that has a 200-fold higher affinity than oxygen to the same binding sites on hemoglobin.⁴³ CO shifts the oxyhemoglobin dissociation curve to the left and alters its shape. In addition, CO binds to cytochrome oxidase, impairing mitochondrial function and reducing adenosine triphosphate (ATP) production. CO thus reduces both the oxygen-carrying capacity of blood and oxygen dissociation at a tissue level, as well as disrupting oxidative cellular respiration. The clinical manifestations with patient symptoms of CO poisoning appear when carboxyhemoglobin (HbCO) levels are more than 15%.⁴⁴ The symptoms are typical of tissue hypoxia, most notably neurologic impairment and myocardial dysfunction (the organ systems most vulnerable to hypoxia). There is no set combination of symptoms that confirms or rules out diagnosis of CO poisoning. The intensity of clinical manifestations varies and does not correlate closely with HbCO levels. Early signs tend to be neurologic. Central nervous system (CNS) injury can lead to progressive and permanent damage. Severe myocardial dysfunction may occur, especially in patients with preexisting coronary disease. The clinical diagnosis of HbCO poisoning should be confirmed by demonstrating its elevated levels. Elevated HbCO levels indicate significant exposure to smoke, which points to the likelihood of chemical airway injury. Low HbCO levels do not always mean minimal exposure, as oxygen therapy in the early stages can reduce levels during transport to the emergency department. Hypoxemia caused by CO poisoning is not detected by pulse oximetry or by partial pressure of oxygen (PaO₂) measurements, and patients may appear "cherry pink" rather than cyanotic. CO-oximetry is required to make the diagnosis. The binding of CO to hemoglobin is stable, with a half-life of 4 hours for a person breathing air.⁴⁵ Increasing the arterial PaO₂ accelerates the CO displacement from the hemoglobin molecule; administration of 100% oxygen at atmospheric pressure shortens the half-life to an average of 74 minutes.⁴⁶ Hyperbaric oxygen therapy has been suggested as a therapy to reduce the neurologic sequelae from CO toxicity. Hyperbaric oxygen therapy achieves faster CO displacement and may be more useful in cases of prolonged exposure, when it also may be assumed that it is harder to displace the toxin bound to the cytochrome system (e.g., mitochondria). The drawback of hyperbaric oxygen therapy is the need to transfer the burn injury patient to a treatment facility equipped with a hyperbaric chamber during the critical period of hemodynamic and pulmonary instability. For these reasons, it may be considered in patients with severe neurologic involvement and levels of HbCO greater than 50%, without extensive burns or severe lung damage, and whose symptoms fail to improve despite a high flow of

oxygen. The lack of availability of hyperbaric oxygen poses a barrier to its use in many tertiary care centers.

Cyanide (CN) is released by the combustion of nitrogen-containing compounds, which are present in plastics, fabrics, and paper. CN acts by binding to cytochrome oxidase, thereby inhibiting the mitochondrial respiratory chain, cell metabolism, and tissue ATP production, resulting in cytotoxic hypoxia and metabolic acidosis. CN toxicity may have a synergistic effect with CO in producing tissue hypoxia. Concentrations of CN greater than 20 ppm are considered dangerous and concentrations of 100 ppm can lead to seizures, coma, respiratory failure, and death.⁴⁷ A rapid diagnostic test for CN poisoning is not widely available; as a result, the treatment of CN poisoning is generally based on clinical suspicion. CN poisoning should be suspected in any patient with a history of smoke inhalation injury with an anion gap metabolic acidosis in the presence of apparently adequate oxygen delivery. Lactic acidosis with a high anion gap can indicate CN poisoning, as can an arteriovenous oxygen saturation difference of less than 10 mm Hg because of the inability of the mitochondria to use tissue oxygen.⁴⁸ Lactic acidosis in burn victims may, however, be due to several causes and is not specific for cyanide toxicity. CN's short blood half-life (~1 hour) makes accurate determination of CN poisoning difficult and is hampered by delayed blood sampling.⁴⁹ Blood CO concentration is highly correlated with CN levels and as such, may be considered as an indicator of CN poisoning. Empirical treatment involves administration of high-flow oxygen. Specific antidotes are advocated, especially hydroxocobalamin, which binds to CN and is relatively nontoxic; but administration must be immediate for any effect to be useful.⁵⁰ The deleterious effects of CN can also be neutralized by the administration of thiosulfate converting CN to thiocyanate, which is excreted in the urine. Exogenous thiosulfate has a slower onset than hydroxocobalamin.⁵¹ The treatment of CN toxicity by administration of nitrites (e.g., amyl nitrite) has generated controversy as this treatment in itself can be hazardous.⁵² Nitrites induce methemoglobinemia which, together with HbCO, may interfere with oxygen transport, thus contributing to hypoxia.

DIAGNOSIS OF INHALATION INJURY

The diagnosis of inhalation injury is based on a combination of clinical findings such as patient history, physical examination, and HbCO levels. Patient history should include the duration of exposure such as whether the patient was found in an enclosed space, unconscious at the scene, or has extensive cutaneous burns. Physical findings include facial burns, singed nasal hair, signs of upper airway injury (hoarseness, stridor, carbonaceous sputum, erythema, and swelling of the oropharynx), and signs of lower airway involvement (dyspnea, tachypnea, wheezing, decreased O₂ saturations). Stridor, dyspnea, increased respiratory effort, and cyanosis appear only once critical narrowing of the airway occurs.

Chest radiographs lack the necessary sensitivity to detect lung damage for inhalation injury in the early stages, but their use is helpful as a baseline for determining future changes.⁵³ Fiberoptic bronchoscopy (FOB) offers a potential means by which to evaluate severity of inhalation injury although it may underestimate the presence of parenchymal disease and controversy exists over whether or not the

visualized severity of the mucosal injury predicts clinically meaningful outcomes.⁵⁴ FOB is unnecessary if subglottic pathology is unlikely. In patients with clinical signs suggestive of thermal airway injury, a normal endoscopic appearance is reassuring although alveolar damage would not be revealed. FOB can be repeated at intervals or if there is clinical deterioration. The presence of soot, mucosal edema, mucosal hyperemia, and pooling of secretions indicates inhalation injury, and suggests the need for close observation with repeated assessment; more ominous signs include narrowing of the laryngeal inlet, mucosal erosion, ulceration, and exudation.⁵⁵ Virtual bronchoscopy is an alternative diagnostic modality to identify inhalation injury; however this is not widely practiced.⁵⁶ Other diagnostic methods include xenon scanning, pulmonary function testing, and computed tomography (CT).^{57,58} The most reliable indicator of the impact of inhalation injury is the arterial partial pressure of oxygen to inspired oxygen fraction (PaO₂/FiO₂) ratio after the resuscitation has started.⁵⁹

Laryngeal injuries are common in burn injury patients and can be associated with long-term morbidity.⁶⁰⁻⁶³ Early recognition of laryngeal injury and consultation with a laryngologist can influence treatment choices (e.g., tracheostomy) and limit morbidity. Because anesthesiologists are most likely to view the larynx of patients with acute burns, it is important to make laryngeal examination part of the initial intubation whether during resuscitation or induction of general anesthesia. Any pathologic laryngoscopic findings should be documented.

TREATMENT

Treatment of upper airway burns secondary to smoke inhalation includes observation and monitoring.

Endotracheal intubation or tracheostomy is indicated if airway patency is threatened. Thermal injury to the oral cavity and supraglottic structures can cause edema; with severe injury, airway obstruction may result as a consequence of edema of the supraglottic airway. Clinically significant obstruction can also occur following fluid resuscitation, with maximal edema typically presenting hours after the initial insult and lasting for several days. There can be no substitute for patience and repeated airway assessment by an experienced anesthesiologist while minimizing edema formation by upright positioning and the avoidance of excessive fluid therapy. As a general rule, when indicated, it is safer to intubate the patient early than risk a difficult intubation after airway swelling has occurred. Although preemptive intubation of patients with inhalation injury can be lifesaving, it should be performed for clear indications. Reasons for intubation include: protection against anticipated airway swelling, treatment of impaired oxygenation and/or ventilation due to lung injury, and to ensure airway protection and optimal oxygenation in cases of hypoxia or CO poisoning with neurologic impairment. The treatment of pulmonary parenchymal injury is inherently more complex than treatment for cutaneous burns. Necrotic skin can be excised, and healing can be observed directly. In contrast, injured lung involves measures to prevent further injury to allow host mechanisms to repair injured tissues. Healing of pulmonary injury is followed indirectly by observations of blood gas analysis and radiographs/CT scans. Adequate oxygenation must be

maintained and bronchial hygiene facilitated. Some patients may benefit from noninvasive ventilation in the absence of usual contraindications.⁶⁴ Endotracheal intubation may be necessary if the patient has increased work of breathing or if gas exchange is compromised.

Patients with both cutaneous burns and inhalation injury may require larger fluid volumes for resuscitation than those without inhalation injury.⁶⁵ Additional fluid resuscitation measures beyond titrating fluid input to maintain adequate urine output (generally considered 0.5-1 mL/kg/h) are not necessary and there are at least theoretical issues that the lung should be maintained “dry” to optimize gas exchange.⁶⁶

Moderate elevation of the head of the bed allows gravity to help reduce airway edema by facilitating venous and lymphatic drainage, and is therefore a sensible, critical standard practice. The patient should be given oxygen by mask to maintain adequate arterial oxygen saturation. Suction should be used to keep the airway clear of debris and secretions. Children are at greater risk of obstruction because of their smaller airways, as are patients whose burns include circumferential burns to the neck. Other early signs and symptoms of respiratory dysfunction may be more suggestive of a more severe inhalation injury.

Respiratory failure is a consequence of inhalation injury; however, the severely burn-injured patient often has multiple mechanisms contributing to lung injury, systemic inflammation in response to burn injury, pulmonary edema from fluid resuscitation, and sepsis. Thus the extent to which inhalation injury impacts burn patient outcome is difficult to separate from the contributions of other injury drivers, which affect the lungs. Management of respiratory failure commonly consists of mechanical ventilation and effective and repetitive pulmonary toilet. A myriad of ventilation strategies exists, and consensus regarding the most appropriate way to ventilate patients with inhalation injury has not been reached.⁶⁷ In all cases, the goal of mechanical ventilation should be to optimize oxygenation and ventilation while minimizing potential ventilator-induced lung injury. The mechanisms of ventilator-induced lung injury include: high airway pressures causing barotrauma, over-distension of alveoli leading to volutrauma, repetitive opening and closing of alveoli causing atelectrauma, and lung inflammation caused by the release of proinflammatory cytokines that produce biotrauma.⁶⁸ The use of lung-protective ventilation strategies (i.e., tidal volume of 5-8 mL/kg predicted body weight, limitation of plateau pressure to less than 28 cm H₂O, and application of sufficient positive end-expiratory pressure to maintain alveolar patency and adequate oxygenation) is recommended as the initial approach if invasive ventilation is required. Studies have shown that lung protective ventilation with low tidal volumes are associated with lower mortality in patients with ARDS and are therefore also recommended in burn injury patients.⁶⁹ As in other critically ill patients, prone positioning has been shown to improve oxygenation in burn injury patients with severe ARDS.⁷⁰ Permissive hypercapnia, where blood carbon dioxide partial pressure (PaCO₂) is allowed to rise (<60 mm Hg) should be considered to limit plateau pressures unless there is a concomitant neurologic injury with suspected intracranial hypertension.⁷¹ These lung-protective ventilation strategies are generally considered to also apply to pediatric patients,

although some evidence exists to challenge this presumption.⁷²⁻⁷⁴ Other strategies used by some burn centers for management of inhalation injury include high frequency percussive ventilation or high frequency oscillation ventilation, either of which may facilitate the clearance of airway debris and secretions.^{75,76} High frequency percussive ventilation and high frequency oscillation ventilation may be considered as “rescue modes” in very severe lung disease, though a benefit on outcome remains unproven. Extracorporeal membrane oxygenation (ECMO) is increasingly used as a rescue treatment for patients with refractory hypoxemia but there is inadequate evidence to support its benefit in inhalation injury at this time.^{78,79}

The consensus recommendations for mechanical ventilation also apply in this context, as do strategies for the prevention of ventilator-associated pneumonia.⁸⁰ Bronchodilators may be administered to help optimize ventilation in the event of bronchospasm. Bronchoscopy may improve pulmonary hygiene and patient prognosis by clearing secretions and sloughed epithelial cells. Although not yet in routine clinical use, there are several promising experimental pharmaceutical adjuncts that address physiologic changes associated with inhalation injury. Aerosolized racemic epinephrine serves as a bronchodilator, vasoconstrictor, and mucolytic agent to alleviate wheezing and bronchospasm caused by the chemical tracheobronchitis.^{81,82} An aerosolized N-acetylcysteine/heparin combination therapy, which acts as both an oxygen free-radical scavenger and a mucolytic agent, has also been successfully used in children and adults with inhalation injury.⁸³⁻⁸⁵ Inhaled nitric oxide causes selective vasodilation in ventilated lung segments, and may improve oxygenation and pulmonary hemodynamics.^{86,87}

Noninvasive positive pressure ventilation (NIV) has been successfully used to avoid endotracheal intubation in select patients with mild inhalation injury with little evidence of edema, or as respiratory support strategy following extubation.^{88,88a} The potential benefits of NIV are numerous including allowing the patient to communicate freely, require less sedation, allow cough and expectoration of secretions, and avoid other potential complications of intubation such as oropharyngeal trauma, mucosal ulceration, and ventilator-associated pneumonia. However, very strict case selection is essential. NIV requires compliant patients who can cough and protect their own airway and it must not be used where there is a risk of airway obstruction, or in patients with facial burns because of the tight mask required. In addition, there are legitimate concerns that NIV may conceal signs of progressive airway obstruction in the setting of an inhalation injury. The use of opioid and sedative drugs, often needed in burn injury patients, may complicate the use of NIV as a consequence of their respiratory depressant effects.

High-flow nasal cannula is a mode of respiratory support increasingly used in the management of acute respiratory failure. This mode delivers humidified gas via a nasal cannula at flow rates exceeding minute ventilation. The benefits include the reduced work of breathing and improved gas exchange by nasopharyngeal dead-space washout; decreasing the energy required to humidify and heat respiratory gases; and providing a degree of positive distending pressure. There are limited reports of its use in patients with inhalation injury.⁸⁹

Acute Management

PATIENT EVALUATION

Optimal management of burn injury patients begins at the scene of injury and continues in the emergency department and with transfer to a specialized burn unit. The primary survey should be performed using a systematic approach that first seeks to identify the greatest threats to life as provided in the Advanced Trauma Life Support (ATLS) and Advanced Burn Life Support (ABLS) guidelines.^{90,90a} This approach requires a combined strategy of airway assessment and protection, initiation of resuscitation, and evaluation for coexisting injuries. Protecting the airway of a thermally injured patient is of the utmost priority. Early intubation is indicated in patients with symptomatic inhalation injury, or any thermal injury to the face, mouth, or oropharynx that threatens airway patency (stridor, swelling on laryngoscopy, upper airway trauma, altered mentation, and respiratory distress).⁹¹ The current criteria for prehospital intubation has been questioned because of the high incidence of over-intubation and early extubation posthospital admission.⁹² Despite this concern, it seems safer to intubate and modify therapy once in hospital rather than be afflicted by airway distress during prolonged transport. Oropharyngeal burns can rapidly cause obstruction; other causes of critical respiratory failure, such as coma, require immediate diagnosis and treatment. Once the airway is secure, breathing assessment follows. Auscultation of breath sounds and determination of respiratory rate and depth are essential for assessing the status of the lungs, chest wall, and diaphragm, and to evaluate the patient's ability to adequately ventilate and oxygenate. Circumferential burns of the trunk or neck may impair respiration and require bedside escharotomy. Continuous monitoring of heart rate, blood pressure, pulse oximetry; and clinical assessment of unburned skin color should be used as parameters to assess circulatory status. An elevated heart rate (100-120 beats/min) is considered within normal limits for adults with burn injury; a higher heart rate should raise suspicion for hypovolemia, other trauma, and inadequate pain management. Circulatory assessment requires evaluation of perfusion of all extremities, paying particular attention to any circumferentially burned extremities. If perfusion is compromised, escharotomy is indicated. Intravenous access should be obtained via peripheral, central, and/or intraosseous routes and may safely be placed through burned tissue if necessary. Adjuncts such as ultrasound may be helpful in placing peripheral intravenous catheters. Large-bore peripheral access is preferred because smaller catheters do not allow faster fluid administration, especially in larger burns.

Fluid management based on weight and burn size should be addressed once total assessment of the injury has been established. Patients who have sustained a thermal injury often present with altered mental status and the possibility of associated injury, substance use, hypoxia, inhalation injury, or a preexisting condition that should always be addressed. As with trauma patients, the Glasgow Coma Scale, which utilizes verbal, motor, and eye measurements, can be used to establish a baseline mental status. Providing adequate environmental temperature control is essential for burn injury patients as they lose their ability to

thermoregulate. The patient must be completely exposed to assess injury and to remove any contaminants that might prolong contact with chemicals or heat sources. A warmed environment and immediate coverage with clean blankets can limit hypothermia during the examination. More than 5% of patients admitted to burn centers have also sustained nonthermal traumatic injuries.⁹³ Therefore all burned patients should be approached initially as multiple trauma patients. Whole-body CT imaging and focused assessment with sonography in trauma-echocardiogram exam should be performed when associated injuries are suspected.

Indicated imaging, laboratory analyses, and adjunctive measures such as urethral catheters and nasogastric tubes should be completed at this time. It is mandatory to perform a rapid primary evaluation and immediately correct any problems found. Once these steps are completed, a more thorough assessment of thermal injury may ensue. The patient's full history should be taken including: detection of the mechanism of injury, consideration of abuse, height and weight, possibility of CO intoxication, and facial burns. In addition, history of previous diseases should be obtained, if possible (allergies, medications, past medical history, events).

Once the primary and secondary surveys have ensured stabilization of the thermally injured patient, transfer to a facility capable of providing the care necessary to support a burn patient is initiated. The American Burn Association has criteria for referral to a specialized burn center that includes both patient and burn characteristics such as size, depth, and etiology (Box 87.1).⁹⁴ Patients who should be referred to a higher level of care for burns include those with partial thickness (second degree) burns greater than

BOX 87.1 American Burn Association Burn Center Transfer Criteria

- Second- and third-degree burns on >10% of TBSA in patients age <10 or >50 years
- Second- and third-degree burns on >20% of TBSA in other age groups
- Second- and third-degree burns that involve the face, hands, feet, genitalia, perineum, and major joints
- Third-degree burns on >5% TBSA in any age group
- Electrical burns, including lightning injury
- Chemical burns
- Inhalation injury
- Burn injury in patients with preexisting medical disorders that could complicate management, prolong recovery, or affect mortality
- Any patients with burns and concomitant trauma (such as fractures) in which the burn injury poses the greatest risk of morbidity or mortality; in such cases, if the trauma poses the greater immediate risk, the patient may be treated initially in a trauma center until stable before being transferred to a burn center
- Hospitals without qualified personnel or equipment for the care of children with burns should transfer the patient to a burn center with these capabilities
- Burn injury in patients who will require special social/emotional and/or long-term rehabilitative support, including cases involving suspected child abuse and substance abuse

TBSA, Total body surface area.

10% TBSA; those with burns of the face, hands, feet, genitals, perineum, or across major joints; and those with full thickness (third degree) burns of any size. Evidence suggests that burn injury patients have improved outcomes if transferred early to a facility capable of providing an advanced level of burn care.^{95,96} Therefore it is important to accurately identify those patients with burns severe enough to merit transfer so that outcomes will be optimized.

Burn centers have been developed to standardize and optimize the overall quality of care delivered to burn-injured patients.⁹⁷ Burn centers provide acute care using a multidisciplinary team that includes burn surgeons, anesthesiologists with special interest in burns, critical care physicians, burn-trained nurses, physical and occupational therapists, pharmacists, and dietitians. In addition, improvements in burn survivors' long-term functional and psychological outcomes and quality of life have resulted from burn units having integrated relationships with physiatrists and rehabilitation facilities as well as burn psychologists and exercise therapists. Since an important part of functional recovery includes returning to work or school, newer additions to the burn team include vocational counselors, recreational therapists, child life specialists, and teachers.

Estimation of Size and Depth of Burn Injury

The magnitude of burn injury is classified according to the percentage of total body surface area (%TBSA) involved, depth of the burn, and the presence or absence of inhalational injury. Accurate estimation of burn magnitude is needed to guide the initial resuscitation strategy, make the referral to a burn center, ascertain the need for surgery, and to estimate prognosis.⁹⁸ Whereas a detailed evaluation of the extent of the thermal injury is assessed during the secondary survey, an early estimate of burn size and depth is needed during the primary survey to calculate initial resuscitation fluid requirements for circulatory support. Three of the most commonly used methods to estimate %TBSA are the "rule of nines," palmar surface area, and the Lund-Browder diagram. The rule of nines is used in adults and is less accurate in children. This method divides the body into body surface areas of 9% (the head, each upper limb, the front of the trunk, the back of the trunk, the front of each lower extremity, and the back of each lower extremity).⁹⁹ The surface area of the patient's palm (excluding the fingers), approximately 0.5% of the TBSA, is used to estimate small (<10% TBSA) burns.¹⁰⁰ However, this method is inaccurate for larger burns. The Lund-Browder diagram is considered the most accurate, if used correctly (Fig. 87.2).¹⁰¹ It allows for the variation in body proportions with age and is used especially in children. Computerized methods have evolved and demonstrate high correlation and reproducibility.¹⁰²

Burn depth is also considered an important determinant of outcome. First-degree burns are limited to the outer layer or epidermis of the skin. The skin usually appears red and dry and is very painful to touch. Healing takes place in 3 to 5 days. Second-degree burns are further categorized into superficial and deep partial thickness burns. A superficial partial thickness burn extends into the superficial papillary dermis and appears red in color with significant weeping and blisters. It will also blanch when pressure is applied, and generally it takes less

than 2 weeks to heal. Deep partial thickness burns extend into the reticular dermis and appear yellow or white and dry and often are extremely painful; however, in some cases, the sensation in the deep partial thickness may become diminished. Full thickness or third-degree burns extend through the entire thickness of the dermis. These may appear dry, leathery, black, or white and are usually painless since nerves and endings are destroyed. They do not blanch under pressure. Although initially painless, the subcutaneous inflammation associated with deep dermal burn often becomes more painful than more superficial burns.¹⁰³ The designation, fourth-degree burns, is used to describe those that have injured deeper structures, such as muscle, fascia, and bone. Deep second-, third-, and fourth-degree burns require surgical debridement and grafting, whereas more superficial burns do not. Since the area of injury may progress over the first 2 to 3 days after the initial insult due to the effects of coagulation and ischemia, burn depth estimation may be greater when examined later compared to the initial evaluation. Close reevaluation may be required to determine the actual burn size and depth.

Fluid Resuscitation

Current fluid therapy is based on knowledge gained over the last century. Major breakthroughs in fluid management were made by Underhill, who described the pathophysiology of burn injury in detail in the 1920s.¹⁰⁴ In 1940, after the Coconut Grove night club disaster in Boston, Massachusetts, the first attempts were made to use intravenous fluids to treat a large group of burn injury patients, and the result was that the mortality was significantly lower than expected. In 1953, the first fluid formula based on the size of the burn and the patient's weight was introduced by Evans.¹⁰⁵ The formula most widely used today is the one that was published in 1974 by Charles Baxter, who was then working at the Parkland Memorial Hospital in Dallas, Texas. The Parkland formula calls for 4 mL/kg/%TBSA of Ringer lactate solution given over the first 24 hours, half of which is given within the first 8 hours from the time of injury.¹⁰⁶ The main advantages of the Parkland formula are use of an easily obtainable fluid (Ringer lactate), low cost, and a strategy that is easy to start and follow. A number of other formulations have been reported over the years, but none has the global impact of the Parkland formula. Some of the more common options are listed in Table 87.1.^{107,108}

Today, few centers in Europe or the United States use formulations other than the Parkland initially.¹⁰⁹ Appropriate resuscitation should be initiated promptly and tailored based on patient parameters to avoid over- and under-resuscitation. Delayed or inadequate fluid replacement results in hypovolemia, tissue hypoperfusion, hypovolemic shock, and multiple organ failure. Morbidities associated with overresuscitation include pulmonary edema, compartment syndromes (muscle compartments, abdomen, and the orbits), and even cerebral edema. As a general rule, burns of less than 15% TBSA can be managed with oral or intravenous fluid administered at 1.5 times maintenance rate (Box 87.2) and careful attention to hydration status. Maintenance fluids, including a source of glucose, should be added to pediatric patient resuscitation fluid as hepatic glycogen stores will be depleted after 12 to 14 hours of fasting.¹¹⁰

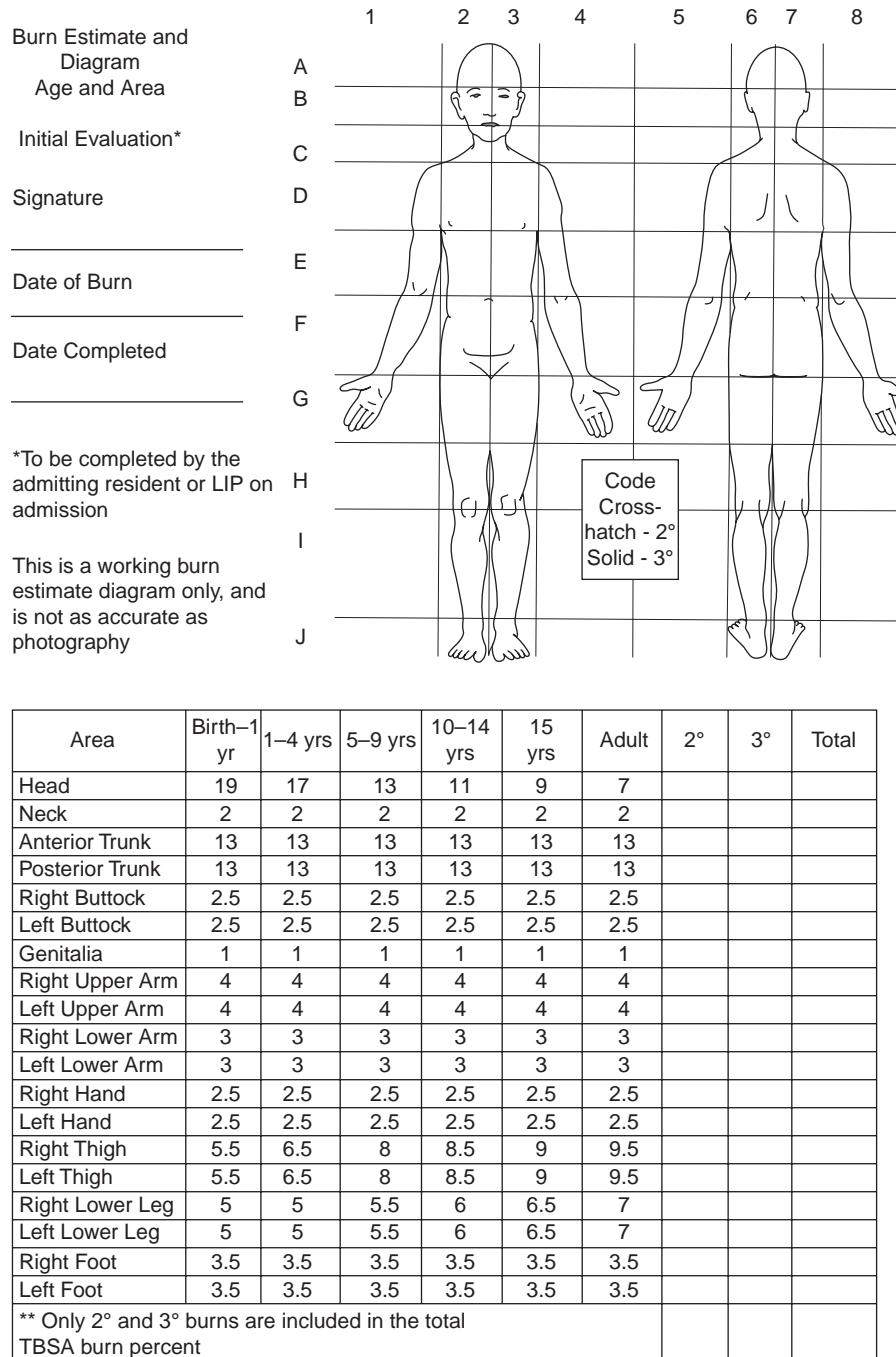


Fig. 87.2 Lund-Browder burn diagram and table. The Lund-Browder burn diagram and table indicate the varying proportions in surface area in persons with different ages. A careful burn diagram should be completed at the time of initial evaluation, including wound size, location, and estimated burn depth. The Lund-Browder chart should be used in pediatric patients because the body surface area relationships vary with age. TBSA, Total body surface area.

Later, when insulin resistance and associated hyperglycemia develops, glucose infusions should be modulated. Colloids have the potential to increase oncotic pressure and thereby reduce fluid shifts and losses. Controversy remains as to the ideal time for initiation of colloid therapy in burn resuscitation. There is a general trend now to initiate colloids earlier than the previously recommended time of 24 hours.¹⁰⁹ All the formulae guide resuscitation with the goal of titrating fluids to obtain a urine output of 0.5 mL/kg/h in adults and 1.0 mL/kg/h in children. The reasons for using

hourly urine output are that it is easily measured (once a Foley catheter has been placed), it reflects glomerular filtration rate and renal blood flow, and it is a surrogate for end-organ perfusion and an indirect correlate of cardiac output.

ENDPOINTS FOR THE FLUID TREATMENT

No matter which formula is used, it should serve only as a guideline, and fluid resuscitation should be titrated to physiologic endpoints. However, the optimal hemodynamic

TABLE 87.1 Formulations for Fluid Treatment

Formulation	Contains
Parkland	Ringer lactate solution 2-4 mL/kg/TBSA% Half the fluid volume given during the first 8 h and the remainder during the next 16 h
Modified Brooke	Ringer lactate solution 2-4 mL/kg/TBSA%
Brooke	Ringer lactate solution 1.5 mL/kg/TBSA% + colloid 0.5 mL/kg + 5% glucose solution 2000 mL/24 h. The PiCCO instrument measures colloid can be albumin or fresh frozen plasma
HYPERTONIC SOLUTIONS	
Monafo	Ringer lactate containing sodium 250 mmol/L. Volume sufficient to produce urine 30 mL/h. Not commonly used in view of the hyperosmolar effects

BOX 87.2 Maintenance Fluid for Children

- 100 mL/kg up to a body weight 10 kg
- Above 10 kg weight, 50 mL/kg are added in the weight range of 11-20 kg
- Above 20 kg weight, add 20 mL/kg for every kg
*Example: Maintenance fluid for a child of 28 kg:
1000 mL + 500 mL + 160 mL, i.e., total 1660 mL/24 h*

targets of initial resuscitation in burn injury patients remain largely unknown. While traditional markers such as blood pressure, urinary output, and cardiac output are helpful, they do not sufficiently reflect the adequacy of regional perfusion and microcirculation. Even when macrocirculatory variables are within therapeutic goals, signs of tissue hypoperfusion may persist.¹¹² Furthermore, microcirculatory alterations have been identified in patients with severe burns, and the severity of these alterations has been associated with a poor outcome.¹¹³

In an effort to address deficiencies in regional tissue perfusion and microcirculation, trials of “goal-directed” resuscitation have been undertaken, in which fluids are increased to normalize acidosis or achieve normal levels of cardiac output or oxygen utilization.^{114,115} This approach initially seemed effective but, in subsequent analyses, has not proved superior to traditional resuscitation, and resulted in administration of increased fluid volumes and the associated complications. This experience has confirmed earlier studies showing that cardiac output and other parameters require 18 to 24 hours to normalize following burn injury no matter what resuscitation strategy is employed.¹¹⁶ Therefore it appears that the optimal resuscitation strategy is to maintain the burn injury patient in a controlled hypovolemic state with an aim to maintain a urine output of 30 to 50 mL/h in adults. Central circulatory variables, such as intrathoracic blood volume index (ITBVI) when using a Pulse Index Contour Continuous Cardiac Output (PiCCO, Pulsion Medical Systems, Germany) system, wedge pressure when using a pulmonary artery catheter, or stroke volume/cardiac output with echocardiography, should indicate hypovolemia during this specific period. The PiCCO instrument measures cardiac output and extravascular lung water by thermodilution. Hence leaky lungs from inhalation injury and during ventilation-perfusion abnormalities it may give incorrect estimates of

cardiac output and extravascular lung water, respectively. When assessing circulation 18 hours after the injury, these central variables of cardiac filling and function will normalize with this resuscitation strategy.¹¹⁶

During the last few years, there have been indications that an increase in under-resuscitation of burn injury patients may be occurring.¹¹⁸ In addition, a recent survey of resuscitation strategies in Europe suggests an increase in the use of vasopressors and inotropes and early use of colloid for burn injury patients.¹¹⁹ While the impact of these changes remains unknown, there are two important issues using such a strategy. First, the skin, which in burn injury is the damaged organ, has a very high density of α 1 adrenoceptors in its vascular bed and secondly, this compartment receives a significant portion of the fluid volume provided by resuscitation, thereby significantly increasing the risk of progression of the burn wound from second- to third-degree injury. There is scientific evidence in humans that support skin ischemia in edematous tissue after fluid resuscitation and this may be assumed to be a significant risk for deepening of the burn wound.¹²⁰

FLUID CREEP/RESUSCITATION FAILURE

A small percentage of patients fail to respond to conventional fluid resuscitation. Signs of resuscitation failure include low urine output, repeated episodes of hypotension or need for vasopressors, worsening of base deficit, or fluid infusion in excess of predicted resuscitation needs in the first 24 hours.¹²¹ When the fluid requirements exceed that calculated by the Parkland formula, administering either albumin or plasma (colloid rescue treatment) instead of or in conjunction with the crystalloid is often recommended to reduce the risk of compartment syndrome.¹²² The risk of abdominal compartment syndrome (ACS) increases appreciably when fluid volumes greater than 250 mL/kg/24 h are exceeded.¹²³

If the total fluid requirement exceeds 6 mL/kg/%TBSA per 24 hours, it is advisable to obtain more information regarding intravascular volume and cardiac function. This usually occurs with very deep burn injury beyond the dermis. Hemodynamic monitoring modalities to obtain this information on cardiac function include transthoracic and/or transesophageal echocardiography, measures of cardiac preload or fluid responsiveness (e.g., stroke volume variation, ITBVI or pulmonary arterial wedge pressure, cardiac index), measures of oxygen delivery and/or consumption (e.g., central venous oxygen saturation [ScvO_2]), serum markers (e.g., base deficit, lactate), and measures of cellular metabolism (e.g., gastric tonometry). The major limitation of routinely using these measures for all resuscitations is that they have not been validated as resuscitative endpoints in the burn injury population; targeting multiple endpoints may result in excess fluid administration.

With large volume resuscitation, monitoring of abdominal, ocular, and extremity-fascial compartments for hypertension should regularly be performed. The most commonly used method to monitor intraabdominal pressure is measurement of intravesical pressure through a catheter inserted in the urinary bladder. The normal range of intraabdominal pressure is less than 5 to 12 mm Hg. Values above 25 mm Hg generally necessitate intervention, whereas values between 12 and 25 mm Hg indicate the need for close observation for

evaluation.^{124,125} ACS is defined as sustained intraabdominal pressure exceeding 25 mm Hg with new-onset organ failure, such as oliguria or decreased lung compliance. It should also be suspected not only in patients with major burns but particularly in those who have received an amount of fluid resuscitation well beyond that predicted based on weight and burn size. In cases of symptomatic intraabdominal pressure or ACS, decompression is necessitated via paracentesis, laparoscopy, or laparotomy.

“Fluid creep” refers to the trend of over-resuscitation in burn injury patients.¹²⁶ Overly aggressive fluid administration may result in pulmonary edema, compartment syndromes, multiorgan failure, nosocomial infection, and increased mortality as well as the extension of the burn injury because of excessive local edema.¹²⁷ Factors that contribute to “fluid creep” include overestimation of the burn size, emphasis on achieving supra-physiologic hemodynamic targets (e.g., base deficit, lactate, cardiac index and/or output, and surrogate markers, such as stroke volume variation), and increased opioid utilization (opioid creep).^{128,129} A hesitancy for reducing the rate of fluid administration in patients with evidence of adequate tissue perfusion such as a urine output greater than 0.5 mL/h in adults or greater than 1.0 mL/kg in children also appears to play a role in fluid creep.¹³⁰ Computerized decision-support tools may be beneficial to decrease the volume of crystalloid infused and, consequently, the incidence of fluid creep and its complications.¹³¹ Such systems reduce over-resuscitation by rapid downward titration of fluid volumes when urine output is adequate.

Strategies to limit fluid creep may include albumin administration during early resuscitation and, more commonly, initiation of “colloid rescue” early (12-24 hours) after the burn injury when capillary integrity is thought to be restored. Hypertonic saline may also be beneficial in limiting fluid volumes, but careful monitoring is needed, as hypernatremia is associated with the development of acute renal failure.^{132,133} High-dose ascorbic acid (vitamin C) may have efficacy in reducing resuscitation volumes and the time to complete resuscitation in severe burns.^{134,135} Its use has not gained traction because of concern for osmotic diuresis and renal failure as well as an association with pseudohyperglycemia.¹³⁶ Exchange transfusion (plasmapheresis) has been attempted but is not currently used.¹³⁷

Electrical Injury

Electrical burns account for up to 4% of admissions to burn centers.¹³⁸ The severity of injury after an electrical burn depends on voltage (V), current, type of current (alternating or direct current), path of current, duration of contact, resistance of involved tissues, and individual susceptibility.¹³⁹ Low-voltage electrical injury is classified as less than 1000 V and can damage tissue at the contact site. High-voltage injury is characterized as more than 1000 V, and leads to damage that extends into the surrounding tissues, particularly to muscle around long bones. Exposure to current generated may also cause cutaneous injury by transformation of electrical energy to thermal energy. Injuries can range from local erythema to full-thickness burns. Burns due to lightning are common but typically quite superficial because of the short duration of contact between the energy source and the victim.¹⁴⁰

Electrical injury should be managed as a multisystem injury. Evaluation for associated traumatic injury, particularly to the spinal cord, should take place, including assessment for event-associated blunt thoracic or abdominal trauma.^{141,142} Patients with high-voltage injuries should also be evaluated for rhabdomyolysis. Limbs should be assessed for compartment syndromes that may require fasciotomy. For treatment of these complications, patients may come to the operating room within 24 hours of injury. In high-voltage electrical injuries, urgent surgery may be life-saving, and is necessary to allow the highest chance for limb salvage. After initial burn wound excision, further debridement may be indicated to ensure adequacy of excision of necrotic tissue before reconstruction. Wound management of high-voltage injuries often requires staged debridement, because the extent of myonecrosis is often difficult to initially ascertain and myonecrosis can extend over time. Wound closure often requires use of grafts and local or distant flaps. High-voltage electrical injuries can be severe resulting in the need for amputations. The tetanic contraction of muscle caused by continued electrical stimulation may cause bone damage including vertebral fractures.

Electrical injury affects the cardiovascular system by directly causing necrosis of the cardiac muscle and by inciting dysrhythmias.¹⁴³ The most frequently encountered rhythm disturbance is sinus tachycardia, often accompanied by nonspecific ST- and T-wave changes. Conduction defects such as heart blocks are also common. Cardiac standstill and ventricular fibrillation are the most serious cardiac complications of electrical injury. Patients without electrocardiographic changes on presentation are unlikely to experience life-threatening arrhythmias.¹⁴⁴ The myocardial injury after electric shock behaves more like a cardiac contusion than a myocardial infarction generally with minimal hemodynamic consequences. Enzyme markers of cardiac injury may be misleading, as normal enzyme concentrations in the circulating blood do not exclude the possibility of a conduction system injury with consequent rhythm disturbances.¹⁴⁵

Patients with major electrical burns should have an individualized fluid resuscitation. Deep tissue injury, including visceral injury with extravasation into extravascular compartments, makes formula-based resuscitation generally inadequate since the surface burn is only a portion of the injury.¹⁴⁶ In addition, the current-induced injury to muscle can lead to rhabdomyolysis and myoglobin release, which can precipitate in the renal tubules causing acute kidney injury. Thus if myoglobinuria is present, urine output should be maintained at 1 to 2 mL/kg/h until the urine is no longer pigmented, at which time urine output can be titrated to 1 mL/kg/h.¹⁴⁷ Additional treatment with sodium bicarbonate, mannitol, and furosemide facilitate myoglobin excretion and protect against renal tubular injury. It is not uncommon for patients with major electrical burns to suffer long-term neuropsychological sequelae such as chronic pain and therapy-resistant psychological symptoms that need to be addressed in an extended rehabilitation process.¹⁴⁸

Chemical Burns

Chemical burns represent only about 3% of burn center admissions, but they are an important source of morbidity.¹³⁸

Most chemical burns in middle- or high-income countries occur in the workplace, but some are secondary to assault, typically to the face. Chemical injuries have some important biochemical differences when compared to thermal burns. In thermal injuries, there is a rapid coagulation of tissue protein due to irreversible cross-linking reactions, whereas in chemical burns the protein destruction continues longer due to hydrolysis mechanisms.¹⁵⁰ These mechanisms may extend as long as traces of the offending agent are present especially in deeper skin layers. In addition, some chemical agents can produce a systemic toxicity. The duration of the chemical's contact with skin is the major determinant of injury severity. The severity of a chemical burn injury is also determined by the concentration of the agent, its tissue penetration, and mechanism of action.¹⁵⁰

The initial management of any chemical exposure is to eliminate the toxic chemical quickly without contaminating care providers. Elimination of the toxic chemical involves removal of clothing and a thorough irrigation with water.¹⁵² In most instances, efforts to neutralize chemicals are contraindicated due to the additional generation of heat, which would further contribute to tissue damage.¹⁵³ Dilution, not neutralization, is the key to therapy. There are two notable exceptions: hydrofluoric acid (sub-eschar injection of 10% calcium gluconate) and white phosphorous (lavage with 1% or 2% copper sulfate immersed in water).¹⁵⁴ Diphoterine is a new chelating agent that has shown initial promise for treatment of chemical burns.¹⁵⁵ The insidious nature of some chemical injuries allows them to progress for prolonged periods so that an initially superficial-appearing wound ultimately requires surgery. A special concern in larger settings of chemical accidents are precautions not to contaminate the emergency department by the chemical in question. Initial cleansing of the chemical is performed outside the hospital doors and such procedures should have an action plan in the hospital disaster management protocols.¹⁵⁶

General support and care involves fluid resuscitation as with a burn injury using urine output monitoring to assess adequacy of end-organ perfusion. Disturbances of pH can occur with systemic toxicity.¹⁵³ Blood gas and electrolyte analysis should be performed until metabolic disorder has been treated and controlled. After lavage and debridement, chemical burns can be treated with topical antimicrobial agents and dressings. Early excision and grafting may be needed albeit the pronounced difficulties in assessing burn depth in these injuries. Inhalation injury may also occur and be present if chemicals are aerosolized and such injuries are managed like smoke inhalation injuries.

Cold Injury

Cold injury or frostbite occurs when tissues are exposed to temperatures below their freezing point (typically -0.55°C) for a sustained period of time.¹⁵⁸ Severity of injury depends on a number of factors including the absolute temperature, duration of exposure, wet or dry cold, immersion, and patient comorbidities such as peripheral vascular disease, neuropathies, smoking, mental health issues, and substance abuse.¹⁵⁹

Cold injury most commonly occurs in the distal extremities or exposed areas of the face. It can result in a wide

spectrum of injuries, ranging from minor injury with complete resolution to the need for major limb amputation. The progression of cold injury evolves over time. The wounds may initially present with blisters that do not appear to be deep. Over days to weeks, because of injury to the microvasculature, they can progress to full-thickness loss; toes and fingers may mummify over prolonged periods.

On arrival to the hospital setting, underlying unstable comorbidities, trauma, or hypothermia must be assessed and managed before frostbitten extremities are treated. Moderate or severe hypothermia should be corrected to bring core temperature above 35°C before initiating frostbite warming. Rewarming the extremities can become extremely painful, so analgesics should be administered.¹⁶⁰ Rewarming is ideally accomplished using a whirlpool bath set at a temperature range of 37°C to 39°C , which decreases the pain experienced by the patient while only slightly slowing rewarming time. Rewarming should continue until a red/purple color appears and the extremity tissue becomes pliable. Loss of sensation after a long period of normothermia is a poor prognostic indicator.¹⁵⁸

If ischemic frozen extremities do not reperfuse after rewarming, early angiography, thrombolysis, and anticoagulation may be warranted.^{162,163} Intravenous vasodilators (nitroglycerin or papaverine) may be useful in conjunction with thrombolysis to address the vasospasm that often accompanies a frostbite injury. Magnetic resonance angiography may be beneficial for prognostication as it allows direct visualization of occluded vessels and surrounding tissue and may show a clearer demarcation of ischemic tissues.¹⁶³ Wound management is generally conservative, allowing ischemic tissues to demarcate before excision. Wound closure often requires skin grafts and local or distant flaps. Prophylactic antibiotics are not indicated since frostbite injuries are not inherently tetanus-prone wounds.

Stevens-Johnson Syndrome/Toxic Epidermal Necrolysis

Toxic epidermal necrolysis syndrome (TENS) and Stevens-Johnson syndrome (SJS) are severe exfoliative diseases of the skin and underlying structures caused by immunologic reactions, usually triggered by a medication or a viral syndrome.¹⁶⁵ Common triggers for SJS and TENS are drug exposure with anticonvulsants, antibiotics, and allopurinol.¹⁶⁶ The two syndromes are distinguished from each other by disease severity, which is characterized by the extent of epidermal detachment and erosions of mucous membranes. The TBSA involved in SJS is less than 10%, 10% to 30% in SJS-TENS overlap, and more than 30% in TENS. Outcomes vary according to the TBSA affected and age. Mortality with TENS is approximately 15% whereas that of SJS is less than 5%.¹⁶⁷ Age, as in thermal burns, is also a major factor affecting outcome in these patients.¹⁶⁸ The primary cause of death is infection and multiorgan failure. Because a burn center has personnel with expertise in the management of patients with skin loss from thermal injury, it often provides care for patients with SJS and TENS. Initial treatment begins with withdrawal of any offending drug and includes airway protection if needed, fluid resuscitation, nutritional support, close monitoring for

septic complications, and eye care.¹⁶⁹ Wound desiccation and superinfection is prevented with topical antimicrobial agents, and selective use of wound membranes can also be considered. Numerous other adjuvant therapies have been tried in TENS management including corticosteroids, cyclosporin, cyclophosphamide, plasmapheresis, pentoxyfylline, N-acetylcysteine, ulinastatin, infliximab, and granulocyte colony-stimulating factors (if TENS-associated leukopenia exists); however their effectiveness is uncertain.¹⁷⁰

Special Considerations

PEDIATRICS

The treatment of children with burn injury differs from burn care in adults in several areas, including airway management, fluid resuscitation, and pharmacologic therapies.¹⁷¹ Children have a greater body surface area to mass ratio than adults, resulting in increased fluid resuscitation requirements (based on body weight), greater evaporative water, and making them more prone to hypothermia. In addition, children have disproportionately thinner skin, which may lead to the risk of deeper burns at lesser temperature. Thinner skin also makes initial burn depth assessment difficult because a burn may initially appear to be of partial thickness but be a full thickness injury or can develop into a full thickness injury.

The circulatory system in infants and children also differs from that of adults. Infants have limited cardiac contractility and are dependent on their heart rate to increase cardiac output. In addition, there is a greater susceptibility to fluid overload, especially in younger children, particularly if all the administered fluids (flush solutions, medications, carrier fluids) are not taken into account. During surgical procedures, it is important to account for the volume of fluid administered subcutaneously for tumescence of donor sites and burn sites. The kidneys of young infants have less concentrating ability. The short length of pediatric intravenous catheters and patient activity can lead to extravasation as the patient develops edema after burn injury. Central lines in children can compromise circulation to extremities and require extra monitoring. Intraosseous lines can result in limb loss due to compartment syndrome from either a misplaced or dislodged catheter, or leakage of infused fluids around the needle insertion site.

The child's body temperature should be closely monitored and ambient temperature increased in the examination room to prevent hypothermia. Warm intravenous fluids and warm blankets are useful adjuncts in this setting. Fluid-based convection heat mattresses can be particularly effective and useful in this scenario. Wet cold dressings and cold intravenous solutions should be avoided to decrease loss of body heat.

Airway and pulmonary considerations in children include their smaller airway, which can rapidly be compromised with airway edema causing resistance to airflow. Infants and small children also lack the pulmonary reserve present in older children and adults. In children with scald injury, respiratory failure can occur during and after fluid resuscitation, even in the absence of inhalation injury.¹⁷² Stridor and retractions should be taken as signs of airway

compromise and a need for intubation. Asthma is prevalent in children and may be exacerbated by smoke inhalation. Bronchospasm, common in children suffering inhalation injury, should be treated early and aggressively.

Children are susceptible to resuscitation-related cerebral edema, which can result in seizures or brain herniation.^{173,174} There is laboratory evidence that the blood brain barrier may be more easily disrupted in children after major burn injury and could thus lead to a larger risk for neurologic dysfunction.

Assessing pain and anxiety is challenging in children because many are unable to verbalize their complaints. Compared to adults, opioid tolerance seems to develop faster in young children.¹⁷⁵ Age-specific pain and anxiety scales exist and should guide care. In general, a child should be upset and crying after burn injury. A moribund or minimally responsive child is likely to be in shock and requires immediate attention. Children are often combative during wound care and dressing changes. During these times, appropriate doses of anxiolytics and analgesics, including ketamine and benzodiazepines, should be administered. However, once the stimulus stops, special attention is needed as children can be oversedated because the half-life of the drug is longer than the duration of painful dressing changes.

Up to 20% of pediatric burn injuries are a result of abuse or neglect. Abuse should always be considered in a child with burn injury, particularly when the injury pattern does not match the history given, in the presence of multiple injuries of different durations, or in cases when there is evidence of delay in seeking treatment. Physical examination indications such as uniform burn depth with sharp borders; symmetrical isolated lower limb and buttock injury; skinfold sparing; absence of splash marks; associated unrelated injuries; and a passive, introverted, fearful child should also raise suspicion and trigger screening by dedicated child abuse teams.

ELDERLY

Older individuals are more vulnerable to burn injury and are less able to compensate from the injury when it occurs.^{176,177} Age is the most important outcome factor besides TBSA. Concurrently, mortality rate, as well as severity of complications, is more pronounced in this group of patients. The propensity of geriatric patients to burn injury is likely the result of impaired dexterity and mobility, impaired vision, and decreased coordination, which also impair their ability to react rapidly and reach safety when faced with danger.

Older adults often have more comorbid medical conditions and therefore take multiple medications that may blunt their response to the physiologic stress of burn injury and increase their risk for complications. Coexisting cardiac and pulmonary disease can result in complications related to fluid resuscitation including pulmonary edema, congestive heart failure, and pneumonia. Close monitoring of respiratory and cardiovascular parameters in older adults is mandatory during fluid resuscitation. The decision to resuscitate should be carefully weighed in older patients with large cutaneous burn injuries, especially in the presence of inhalation injury, because mortality rates can exceed 90%.¹⁷⁸ Advanced directives, healthcare proxies, and families should be consulted as early as possible.

Older burn injury patients have a lower threshold for ventilator support during treatment because of the decrease in lung reserve. Preexisting renal disease can result in greater sensitivity to nephrotoxic drugs. Older patients also have an altered and impaired immune-response and thereby an increased susceptibility to infection.¹⁷⁹

The skin of older patients is thinner and more susceptible to deeper burn injury. In addition, there is impaired capacity for dermal and epidermal regeneration, so harvesting and especially repeated harvesting of donor skin may not be possible because of poor wound healing. Under normal circumstances, older patients have a reduced resting metabolic rate and may be unable to generate the required increase in metabolic response following a burn injury. For even a minor burn injury, they may benefit from nutritional support and may gain benefit from nutritional rehabilitation prior to surgical treatment.¹⁸⁰ Care should be taken with enteral feeding as it poses a risk of aspiration, particularly in delirious older burn victims. Pain control in the older patient is often inadequate following burn injury, and the premise that there is less pain with increasing age is without foundation.¹⁸¹ Finally, older patients may live alone or have a spouse who is unable to provide the care needed after discharge, including wound care, transportation, and support.

OBESER PATIENTS

Management of the morbidly obese patient poses many clinical challenges including accurate measurement of burn size, resuscitation requirements, mechanical ventilation settings, drug dosing, mobilization, and effective nutritional goals. During resuscitation, obese burn injury patients take a longer time to reach end points of resuscitation and normalize their metabolic derangements.¹⁸² This finding is consistent with findings in the trauma literature in the obese population.¹⁸³ This group can have persistent metabolic acidosis during the resuscitation phase and are at greater risk of developing more severe multiple organ failure.¹⁸² These factors may contribute to higher mortality risk in the morbidly obese burn patient.^{182,185} It remains unclear as to whether actual or ideal body weight is appropriate for estimating fluid requirements accurately. The use of actual body weight to drive resuscitation volumes may result in over-resuscitation of these patients, depending on the resuscitation formula.¹⁸⁷ However, actual body weight and TBSA provide a reasonable starting point, after which fluid rates should be reduced hourly to meet individual needs while preventing burn shock or other complications. In contrast to morbid obesity, mild obesity, for reasons unclear, seems to have a better survival.¹⁸⁸

Infection Control

Infection is a leading cause of morbidity and mortality in burn injury patients because of their increased susceptibility to infection through multiple mechanisms, including altered immunity, loss of the physical barrier of intact skin, damage to the lining of the respiratory tract from inhalation injury, altered gut permeability, and invasive devices. These devices include endotracheal tubes (ETTs), intravascular catheters, and urinary catheters, which bypass the

body's normal defense mechanisms. Sources of organisms that can cause hospital-acquired (nosocomial) infection include the patient's endogenous flora, exogenous environmental sources, and transmission by healthcare personnel. Pneumonia, central venous lines, and burn wounds are the most common sources of bloodstream infections, which typically occur within a week of injury.

Preventative measures against infection are critical for the burn injury patient and include early excision of burn eschar to improve local perfusion and prevent microbial colonization, prudent use of invasive devices, application of antimicrobial burn dressings, and diligent compliance with infection control practices. To avoid selection of resistant pathogens, prophylactic systemic antibiotics should not be administered.¹⁸⁹ For patients with documented infection, antibiotics should be culture-directed. Knowing incidence and sensitivities to unit specific pathogens will allow more accurate targeting of empirically prescribed antimicrobials. Dosing should be adjusted to account for the altered organ function. Regular monitoring of antibiotic levels is important as evidence suggests that many patients never achieve the recommended therapeutic antibiotic concentrations.

Topical antimicrobials consist of a wide range of agents targeted at reducing the incidence of wound infection by controlling microbial contamination at the wound surface. An advantage of local antimicrobial therapy is the ability to get high concentrations of the active agent at the site. Systemic agents are less successful in treating local infections because they most often do not reach the burn wounds in large concentrations because of the microthrombosis of vessels and wound edema. Eschar penetration, safety profile, desired spectrum of activity, patient tolerance, and projected length of therapy must be balanced.¹⁹⁰ Silver nitrate, silver sulfadiazine, and silver-based dressings are the most commonly used agents. Silver works quickly and may have one of the broadest spectra of activity that includes gram-positive, gram-negative, and fungal organisms. Mafenide is an alternative topical agent that offers the added benefit of eschar penetration for deep burns. Although rare, adverse reactions from mafenide can occur in sulfa-allergic patients and metabolic acidosis from carbonic anhydrase inhibition has been reported.¹⁹¹

Early recognition and treatment of sepsis may reduce the incidence of complications and improve survival. Identifying sepsis can be challenging in light of the hyperdynamic, hypermetabolic, and proinflammatory response to burn injury. Systemic inflammatory response syndrome criteria have poor correlation with infection in burn injury patients, with more than 90% of patients fulfilling criteria regardless of clinical stability or infection status.^{192,193} Standardized criteria for diagnosis of sepsis and infection-related diagnoses were developed more than a decade ago for burn injury patients.¹⁹⁴ These burn-specific criteria for sepsis include (three of the following with documented infection): temperature over 39°C or under 36.5°C, tachycardia greater than 110 beats/min or more than 2 standard deviations from value for age, progressive tachypnea (spontaneous ventilation: respiratory rate >25 or as necessary for mechanical ventilation), hyperglycemia (plasma glucose ≥ 230 mg/mL) in the absence of diabetes mellitus, thrombocytopenia (will not apply until 3 days after initial resuscitation; platelet count $\leq 100,000$ μ L), and the inability to continue enteral

feeding for more than 24 hours. Other clinical indicators of sepsis may include increased fluid requirements, hypotension, altered mental status, and worsening renal status. It is likely that use of multiple indicators of sepsis will improve the sensitivity and specificity of early sepsis diagnosis in this clinically more difficult setting.¹⁹⁵

Burn wounds are particularly known to be tetanus prone. Patients who are current with vaccination status require no further treatment while those with unknown or inadequate vaccination status should receive tetanus toxoid in addition to tetanus immune globulin.^{196,197}

Metabolic Considerations

The hypermetabolic response after burn injury is more severe and sustained than any other form of trauma. Burn injury patients have increased resting energy expenditures, increased myocardial oxygen consumption, marked tachycardia, increased body temperature, glycolysis, proteolysis, lipolysis, and futile substrate cycling.¹⁹⁸ Marked and sustained increases in catecholamine, glucocorticoid, glucagon, and dopamine secretions are thought to initiate the cascade of events leading to the acute hypermetabolic response with its ensuing catabolic state. The role of DAMPS in this hypercatabolic state has not been elucidated.¹⁹⁹ The metabolic rate of patients with greater than 40% TBSA burn can exceed 180% of non-burned levels during admission and 150% at the time of complete wound healing.²⁰⁰ Furthermore, the hypermetabolic response to burn injury persists well beyond wound closure, with metabolic and inflammatory changes that can occur up to 3 years after the injury, especially in children with very large burns.²⁰¹ This high metabolic demand and energy expenditure results in the catabolism of lean muscle mass, which may have important detrimental effects for the complete recovery processes.¹⁹⁸

The relevance of the postburn hypermetabolic and inflammatory effects includes prolonged insulin resistance, increased fracture risk, increased liver size due to steatosis, growth impairment, increased cardiac work and dysfunction, protein catabolic state, and impaired muscle strength, hormonal abnormalities, and increased risk for infection. Consequently, severe burn injury is not an acute illness but rather a chronic health problem. Numerous strategies have been employed to modify this catastrophic response including early excision and grafting, thermoregulation, and early aggressive enteral feeding. There are several proven pharmacologic approaches to attenuate the hypermetabolic flow phase of a burn. Adrenoceptor blockade (most commonly with the nonselective β -blocker, propranolol) has favorable effects on heart rate, resting energy expenditure, oxygen consumption, and net muscle-protein balance.²⁰³ Insulin therapy promotes maintenance of muscle mass and improved donor site healing, without increasing hepatic triglyceride synthesis. It also attenuates the inflammatory response.²⁰⁴⁻²⁰⁶ Oxandrolone, a synthetic androgen, has been shown to increase both muscle protein synthesis and muscle strength as well as improve bone mineral content, and is today recommended in burn care guidelines.²⁰⁷ Despite these pharmacologic therapies, muscle wasting of burn injury persists for several years. More research is needed to better manage these functional deficits.

Nutrition

Nutrition is of critical importance for the burn injury patient. It has been estimated that a patient's basal energy needs may benefit up to 200%.²⁰⁸ Nutritional support not only partially abates the hypermetabolic response and attenuates muscle protein loss but also modulates stress hormone levels, improves gut mucosal integrity, improves wound healing, and decreases the risk of stress ulcer formation. Growing evidence suggests that early nutrition is safe, efficacious, and leads to better outcomes. In addition, evidence suggests that delay in enteral nutrition leads to a higher incidence of gut mucosal atrophy, microbial translocation, which can lead to sepsis, and multiorgan failure. The potential disadvantage of early feeding is a higher risk of complications when the patient is being resuscitated from burn shock. Gastric ileus is not uncommon in the early phase, and feeding could lead to a higher risk of aspiration. In addition, there is a concern that burn injury patients who are still in shock may be at risk of intestinal necrosis if fed.

Enteral nutritional support should be used in preference to parenteral nutritional support. Parenteral nutrition should be reserved for those with prolonged ileus and/or enteral feeding intolerance. Oral feeding is preferred to enteral feeding (liquid formulae given through nasoenteric tubes) because of the reduction in both cost and complications. However, the severely injured are unable to eat enough to satisfy the hypermetabolic response. While underfeeding can result in complications, it is important to recognize that overzealous nutritional support offers little additional benefit and may be harmful. Overfeeding can result in fluid and electrolyte imbalances, hyperglycemia, and hepatic steatosis. Although formulae exist to predict total caloric requirements, these often lead to underfeeding during periods of highest energy utilization and to overfeeding late in the treatment course. As there is also a large interindividual variability, actual caloric requirements should be determined by measuring resting energy expenditure with indirect calorimetry.²⁰⁹

Patients who suffer from extensive burn injury will often undergo multiple operative procedures often under general anesthesia. Historically, the use of general anesthesia requires patient's to be nil per os (nothing by mouth, NPO) at midnight of the intended procedure day. This practice can lead to a major void in a burn patient's caloric support. The feasibility and safety of continuing enteral feeding throughout operative procedures has been studied.²¹⁰ Enteral feeding using post-pyloric tubes has been successful, provided the airway was secured via a cuffed ETT or tracheostomy (to prevent aspiration of gastric contents).^{211,212} Nevertheless, it is prudent to hold enteral feedings when there is potential for increasing abdominal pressure (e.g., prone position or surgery on the abdomen) or when an airway procedure such as tracheostomy is to be performed.

Anesthetic Management

PREOPERATIVE EVALUATION

Patients are often brought to the operating room in the early phase of burn injury, when they are undergoing significant

BOX 87.3 Major Perioperative Concerns for the Burn Patient

- Age of patient
- Extent of burn injury (total body surface area, depth, and location)
- Mechanism of injury
- Elapsed time from injury
- Associated injuries
- Inhalational injury and/or lung dysfunction
- Adequacy of resuscitation
- Coexisting diseases
- Airway patency
- Difficult vascular access
- Gastric stasis
- Altered drug responses
- Altered mental states
- Pain/anxiety
- Presence of organ dysfunction
- Presence of infection
- Susceptibility to infection
- Hematologic issues (anemia, coagulopathy)
- Magnitude of surgical procedure

fluid shifts with corresponding cardiovascular instability and/or respiratory insufficiency. Early excision of dead/necrotic tissue with temporary or permanent coverage of the open areas is important for decreasing the burden of wound colonization and systemic sepsis. In addition to standard preoperative evaluation, there are specific features of the history and physical examinations, which deserve additional focus in the burn injury patient. These include the time and extent of burn injury, airway evaluation, presence of inhalation injury, quantity of fluid received, current resuscitation regimen and the patient's response, vascular access/sites, and tolerance of enteral feeding and NPO status (Box 87.3). Communication with the surgeons and the critical care team is crucial to manage perioperative care in a manner that is compatible with treatment goals of the intensive care unit (ICU). Details of the surgical plan, including the extent and anticipated duration of the procedure, are also essential to estimate blood loss and to plan appropriate vascular access, invasive monitors, arrange thermoregulation, and to order appropriate blood products. Conferring with the nurse taking care of the patient will provide valuable information about the current status of the patient.

Intraoperative Management

AIRWAY MANAGEMENT

Airway management in the burn injury patient may be challenging and warrants particular consideration (see Fig. 87.2). Key features of airway assessment include preexisting airway abnormality, current airway injury (i.e., inhalation injury), and signs of glottic obstruction. The type of airway abnormalities may vary depending on the stage of the injury. In the acute burn setting, mandibular mobility and mouth opening may be limited because of edema or, in later care, the developing contractures. Preanesthetic assessment of the patency and soft-tissue compliance of the



Fig. 87.3 Burn-injured patient with a severe neck contracture undergoing general anesthesia with a laryngeal mask airway.

airway are essential. Palpation of the neck and submandibular space may reveal tightness that will limit displacement of the tongue and soft tissues into the submandibular area, making laryngoscopy challenging. Dressings and nasogastric tubes may make face mask seal difficult. Facial wounds may be painful, and exudate and topical antibiotics may result in a slippery skin surface and difficulty holding the mask. Burn victims, who are beyond the acute phase of injury, may have significant scarring and contractures in the face, mouth, nares, neck, and chest, which can make airway management very difficult.^{213,214} The airway sequelae of burn and inhalation injury or tracheostomy can also include subglottic stenosis, tracheomalacia, granuloma formation, obstruction of the nares, and fixation of the neck in a flexed position. If a patient is suspected to be difficult to mask ventilate, it is wise to either confirm the ability to mask ventilate prior to giving drugs that promote apnea or maintain spontaneous ventilation throughout the induction and intubation. The utility of traditional adjuncts used to facilitate mask ventilation, such as an oral airway, nasal airway, jaw thrust, chin-lift, and two-hand mask ventilation, may be limited in the burn injury patient. An oral airway may be difficult to insert in patients with microstomia, as would a nasal airway in patients with scarring of the nares. Chin-lift and jaw-thrust may be impossible because of scarring and contractures, which can limit neck extension and anterior displacement of the mandible.

The laryngeal mask airway (LMA), a supraglottic airway device, has been successfully used as both an alternative to tracheal intubation and a rescue airway device for burn injury patients (Fig. 87.3).²¹⁵ Use of the LMA for airway management may help avoid further laryngeal injury associated with tracheal intubation. It can also serve as an aid to fiberoptic intubation. However, microstomia and fixed neck flexion from contractures can limit its use. Microstomia can impair the ability to insert the LMA into the oropharynx. Fixed neck flexion makes insertion difficult because the distal end of the LMA abuts the chest wall. Surgical release of neck contractures under local anesthesia prior to intubation may be required in severe cases.

If the preoperative examination reveals concern for upper airway patency, mobility, or mask ventilation, fiberoptic



Fig. 87.4 Pediatric patient with burns of the face and neck. The patient underwent early tracheostomy due to profound swelling of the airway present.

intubation while maintaining spontaneous ventilation should be considered. If the patient is uncooperative, inhalational induction or the use of ketamine preserving spontaneous ventilation may permit the advancement of the fiberoptic scope. It is important to avoid gag and laryngospasm during the fiberoptic intubation. Traditional methods to topicalize the airway to prevent gag include using preinduction nebulized lidocaine or lidocaine gargle and postinduction lidocaine sprayed directly on the vocal cords via the fiberscope. Video laryngoscopy is an alternative intubating tool that also permits assessment of hypopharyngeal and glottic anatomy. In children awake intubation is not a viable option. Ketamine-induced sedation/anesthesia maintains the pharyngeal muscle tone and can be used for fiberoptic intubation in children. Tracheostomy completely done under local anesthesia is also at times a viable option (Fig. 87.4). A surgeon capable of performing a potentially difficult tracheostomy should be readily available when there is any question of inability to manage a patient with an anticipated difficult airway. The distorted anatomy can make a surgical tracheostomy difficult in both elective and urgent situations.

Gastric emptying may or may not be delayed in burn injury patients.²¹⁶ Sepsis, intestinal edema, and opioids may slow gastric emptying, with increased risk of aspiration. If there is concern for ileus, rapid sequence induction is generally required. The use of the LMA in the presence of decreased chest or abdominal compliance can result in redirection of ventilated volume from the lungs to the stomach. Regurgitation of gastric contents can occur in these instances significantly complicating the procedure.

It is essential to secure the ETT to avoid unintentional extubation. Traditional securing methods using adhesive tapes or ties are unsuitable in patients with facial burns since tape or ties crossing burned areas can irritate the wound or cause injury to grafts. Placement of a circumferential tie around the patient's head, using wire to secure the tube to a tooth, or use of arch bars can provide safe fixation.²¹⁷⁻²²⁰

The use of cuffed ETTs in the pediatric burn population, both in the operating room and in the ICU, is safe and

recommended regardless of the child's age.²²¹ Considerable fluctuation in airway diameter can occur throughout the patient's acute hospital course because of laryngeal, tracheal, and bronchial edema. With fluctuations in airway diameter, the ETT cuff may need to be readjusted to facilitate mechanical ventilation without a leak or prevent overpressure in the cuff, which can cause tracheomalacia.

Severely burn-injured patients may require tracheostomies because of potential complications from long-term translaryngeal intubation for mechanical ventilation. The optimal timing and indications for tracheostomy remain unresolved.²²² In general, early tracheostomy should be considered if prolonged mechanical ventilation is anticipated (inhalation injury, advanced age, chronic pulmonary disease, other significant systemic comorbidities, and large burn size). Complications can occur, particularly when tracheostomies are performed under nonelective conditions, through burned tissue or in the presence of edema. Tracheostomy-related dysphagia, dysphonia, and other laryngeal pathologies have been described in burn injury patients.²²³

VASCULAR ACCESS

Vascular access in burn injury patients can be challenging. The anatomy of typical vascular access sites can be distorted by the burn injury and in the setting of acute injury, patients can be hypovolemic, making venous access technically difficult to obtain. In addition, resuscitation can result in edema. In pediatric patients, the task can be even more difficult. It may be necessary to place vascular catheters through burn-injured tissue or wounds. On occasion, it may be necessary to have the surgeons debride the insertion site just before placement of the vascular catheter. If no intravenous access is available, temporary intraosseous cannulation may safely be placed in patients of any age. This technique obviates the need for venous cutdowns and can be useful in emergency situations. A multiport central venous catheter is usually necessary in patients with large burn injuries because of incompatibility of resuscitation fluids with drugs, blood, and the need for hyperalimentation. Localization of vessels using ultrasonographic guidance can be useful in placing peripheral and central catheters in patients when access is difficult.²²⁴

Because burn injury patients undergo multiple surgical procedures during their hospitalization, access is required multiple times. Central venous catheters can be kept in place without changing them for more than 7 to 14 days, provided extreme aseptic techniques are practiced during their insertion and use. When a new catheter is needed, the insertion can be rotated and include the jugular, subclavian, and femoral veins. For excision and grafting procedures, securing adequate vascular access before the surgical procedure begins is necessary as blood loss can be rapid and substantial.

VENTILATOR MANAGEMENT

Respiratory failure is common after serious burns caused by inhalation injury, due to inflammatory mediators from the burn, effects of fluid resuscitation, and infection. In providing intraoperative mechanical ventilation, the same considerations used in the ICU must be followed to avoid

barotrauma. Although the concept has not been tested in this population, growing evidence supports the importance of maintaining lung protective ventilation even in the operating room. During the hypermetabolic state (beginning ~48-72 hours after burn injury), oxygen consumption and carbon dioxide production can be significantly increased. Consequently, minute ventilation can exceed 20 L/min in an adult patient with a large burn.

Extensive excision and grafting procedures may result in such a physiological disturbance that postoperative mechanical ventilation is needed. The reabsorption of tumescent fluid used during surgery and the surgery-induced bacterial and cytokine release can aggravate the lung dysfunction. The decision to wean from mechanical ventilation and extubate after surgery is based on the same considerations as in the nonburn patient. Extubation should not be performed in the presence of hemodynamic instability, significant metabolic derangement, hypothermia, sepsis, or worsening pulmonary function. Assessment of extubation readiness should include assessment for edema in the upper airway and glottis. The presence of a good air leak after deflation of the endotracheal cuff is an indirect estimate of an adequate glottic opening. Direct visualization using direct laryngoscopy or with flexible FOB is often performed in the operating room prior to planned weaning and extubation.

MONITORING

As with any patient suffering from multiorgan dysfunction, intraoperative monitoring of the burn injury patient depends on the patient's physiologic status and extent of planned surgery. The injury *per se* can make placement of these monitors challenging when standard sites are burned or are within the surgical field. Difficulty may be encountered in adherence of standard electrocardiogram (ECG) electrodes as a result of exudation of fluid from the injured sites or the presence of topical antibiotic ointment. Use of needle electrodes or surgical staples to fix the electrodes can be effective. Alternatively, placing the electrodes on the back or dependent sites may hold them in place. Application of pulse oximetry probes can also be difficult and may require alternative sites, such as the ear, nose, or tongue in such circumstances. In an extensively burned patient, a blood pressure cuff may have to be placed directly over injured or recently grafted tissue. In this circumstance, great care should be taken to protect the underlying area and a sterile cuff should be used. If rapid or extensive bleeding is expected, an arterial line should be considered for continuous measurement of blood pressure and blood sampling. In addition, the arterial pressure waveform and its alterations in relation to respiration provide continuous hemodynamic information about fluid responsiveness and cardiac output and can be used to guide volume and vasoactive therapy.²²⁵ Temperature monitoring is imperative as these patients are susceptible to and intolerant of hypothermia. Monitoring of body temperature is also useful for detection of blood transfusion reactions intraoperatively (>2°C rise in temperature). Neuromuscular function monitoring in patients receiving neuromuscular blocking drugs is required as dose requirements can be significantly altered. However, continuous use of muscle relaxants

during burn surgery is seldom needed. Multiport central venous catheters are useful for simultaneous monitoring of central pressures and administering of drugs and fluids. Meticulous care to prevent contamination from exogenous sources of all existing or planned introduction of catheters and tubes should always be observed.

PHARMACOLOGIC CONSIDERATIONS

Burn injury causes pathophysiologic changes in the cardiovascular, pulmonary, renal, and hepatic systems, as well as in concentrations of circulating plasma proteins as a result of the release of endogenous mediators, and hormones together with exogenous ligands that are administered affect receptor plasticity. These changes result in altered pharmacokinetic and pharmacodynamic responses to many drugs, and these responses may vary depending on the burn severity and the time elapsed after the injury.^{226,227}

The two distinct phases of cardiovascular and metabolic responses to burn injury can affect pharmacokinetics in different ways. During the acute injury phase (0-48 hours), there is rapid loss of fluid from the intravascular space, resulting in decreased cardiac output and blood flow to organs and tissues. Despite adequate resuscitation, patients may continue to have decreased cardiac output and decreased renal and hepatic blood flow. During this phase, there will be decreased elimination of some drugs by the kidney and liver. Because of decreased intestinal blood flow, absorption of oral drugs will also be delayed. Following the resuscitation phase, the hyperdynamic phase begins, which is characterized by increased cardiac output and increased blood flow to the kidneys and liver. Drugs dependent on organ blood flow will have increased clearances; drug doses may have to be adjusted upward accordingly.

The two major drug-binding proteins, albumin and α -1-acid glycoprotein (AAG), are altered in opposite ways after burn injury.²²⁷ The concentration of albumin, which binds to mostly acidic and neutral drugs, is decreased in burn injury patients while AAG, which binds cationic drugs, is an acute-phase reactant and its concentration increases twofold or greater in these patients.²²⁹ Cationic drugs (lidocaine, propranolol, muscle relaxants, and some opioids) bind to AAG, resulting in decreases in free fraction. Most likely related to the decreased albumin levels and continued fluid leak through burn wounds and/or resuscitation fluids, there is an increase in volume of distribution of almost every drug studied (propofol, fentanyl, muscle relaxants). In addition, pharmacodynamic changes at target organs alter drug-receptor interactions causing variable and at times unpredictable changes in responses to drugs. Consequently, changes in the usual dosages of drugs or complete exclusion of other drugs (e.g., succinylcholine) may be necessary to ensure efficacy, patient safety, or avoid toxicity.

Clearance of drugs highly extracted by the liver depends primarily on hepatic blood flow and is relatively insensitive to alterations in protein binding. Thus clearance of highly extracted drugs (e.g., propofol, fentanyl) may decrease during the early postburn phase as a result of hypoperfusion from hypovolemia and hypotension, and subsequently increase during the hyperdynamic phase when hepatic blood flow increases.^{230,231} During the hypermetabolic phase, renal blood flow and glomerular filtration rate

increase. Thus renal clearance of some drugs (antibiotics [gentamicin, cephalosporins] and H₂-receptor antagonists [ranitidine]) will have enhanced elimination.^{232,233} In contrast, clearance of drugs that have a low hepatic extraction coefficient is unaffected by changes in hepatic blood flow, but is sensitive to alterations in plasma protein levels as it is the unbound fraction of drug that is metabolized. Hepatic enzyme activity also appears to be altered in patients with burns.²²⁶ Phase I reactions, which include oxidation, reduction, hydroxylation, and demethylation, are impaired after burn injury (e.g., diazepam). Phase II reactions involving conjugation, glucuronidation, and sulfation seem to be relatively unaffected (e.g., lorazepam).²³⁵ Additionally, systemically administered drugs may leak out through the burn wound, and blood loss during surgery can potentially exaggerate the elimination of drugs.

ANESTHETIC DRUGS

Many inhalation and intravenous drugs have been used successfully for the induction and maintenance of anesthesia in burn injury patients.²³⁰ Choice of drug should be based on the patient's hemodynamic and pulmonary status and the potential difficulty in securing the patient's airway. Because of its rapid onset and lack of pungency, sevoflurane offers advantages for smooth inhalation induction in children or adults with abnormal airways or those without intravenous lines. The choice of volatile anesthetic does not appear to influence outcome in these patients. Long-term sequelae of repetitive anesthetics in pediatric patients is unknown.

Propofol clearance and volume of distribution are increased in patients with major burns during the hyperdynamic phase of injury.²³⁰ Therefore in comparison with nonburned patients, those with major burn injury may require larger bolus doses and/or increased infusion rates of propofol to attain or maintain therapeutic plasma drug concentrations. Attention to the hemodynamic consequences of administering larger doses of propofol is warranted.

Opioids

Opioids are the mainstay of analgesia in this population of patients because (1) they are potent, (2) the benefits and risks of their use are familiar to the majority of care providers, and (3) they provide a dose-dependent sedation that is beneficial during painful and anxiety-provoking wound-care procedures.²³⁸ The wide spectrum of opioids available for clinical use provides dosing flexibility (i.e., variable routes of administration, time until effect, and duration of analgesia), which can target different pain qualities and contexts. For example, oral opioids with delayed systemic uptake (e.g., sustained-release morphine, fentanyl patch) or prolonged terminal half-life (e.g., methadone) are effective in treating background pain. In contrast, short-acting agents with rapid onset (e.g., intravenous fentanyl, alfentanil) are better suited for procedural pain alleviation. During the acute phase of injury, potent opioids such as morphine sulfate, hydromorphone, and fentanyl should be given intravenously and titrated based on patient response. It is not clear that the use of any one opioid offers fewer side effects than another.

Many patients are receiving continuous infusions of opiates and sedatives before surgery. These infusions have

been maintained to reach a steady state of effect and should not be stopped. Intraoperative analgesia can be achieved by increasing these infusions or turning to other drugs. Fentanyl is commonly used as an analgesic in the operating room as well as for sedation in burn care units. The volume of distribution and clearance of fentanyl are increased following burn injury partly explaining the increased dose requirement of this drug.^{239,240} A decreased volume of distribution and clearance of morphine has been reported in burn patients, with an expected increase in elimination half-life.²⁴¹ However, other literature has suggested no significant difference in morphine pharmacokinetics between adults with and without burn injury.²⁴²

Patient-controlled analgesia (PCA) with intravenous opioids has been shown to be a safe and effective method of opioid delivery for acute or procedure-related pain in both children and adults with burn injury.²⁴³⁻²⁴⁶ PCA also provides benefit by allowing the patient to retain some degree of control over his/her medical care (i.e., control coping).

The analgesic efficacy of opioids decreases with time resulting in the need for increasing dosage requirements to achieve an equivalent effect. Opioid tolerance, a diminished opioid anti-nociceptive effect following repeated exposure to opioid, may be apparent as early as after 1 week of uninterrupted opioid use.¹⁷⁵ It is not uncommon for these patients to manifest opioid tolerance requiring dosage amounts that far exceed standard textbook recommendations.²⁴⁸ Studies with burned animals have suggested intrinsic pharmacodynamic opioid receptor alterations. These include desensitization and downregulation in μ -opioid receptors, and upregulation of protein kinase C- γ and N-methyl-D-aspartate (NMDA) receptors.²⁴⁹ In view of the NMDA upregulation following burns, it is not surprising that ketamine requirements to anesthetize patients also are increased following burn injury.²⁵⁰ Adverse effects of opioids, such as respiratory depression, acute opioid tolerance, and hyperalgesia, particularly with the need for rapidly escalating doses, have generated increasing attention to multimodal strategies. Clonidine, dexmedetomidine, ketamine, and methadone have been found to be effective in the treatment of pain in patients with extreme tolerance to morphine.^{251,252}

A variety of non-opioid analgesics are useful for treating burn pain since their benefit and side effect profiles differ from opioid analgesics (Table 87.2).

NSAIDs

Acetaminophen and nonsteroidal antiinflammatory drugs (NSAIDs) are useful first-line analgesics for minor burns.²⁵³ However, NSAIDs and acetaminophen exhibit a ceiling effect in their dose-response relationship, rendering them inadequate as a single agent for the treatment of severe burn pain. NSAIDs can also have deleterious effects including bleeding risk, gastrointestinal, cardiovascular, and renal complications. As a consequence, NSAIDs are generally avoided in patients with major burns.

α 2 Agonists

Clonidine or dexmedetomidine (α 2-adrenoceptor agonists) can be useful analgesic adjuncts without causing respiratory depression.²⁵⁴ However, the α 2-adrenoceptor agonists can cause hypotension in higher doses and in the presence of hypovolemia; therefore these should not be

TABLE 87.2 Sedation and Analgesia Treatment Guideline

Stage of Injury	Background Anxiety	Background Pain	Procedural Anxiety	Procedural Pain
Acute burn mechanically ventilated	Midazolam infusion or Dexmedetomidine infusion Antipsychotics Propofol infusion	Morphine infusion	Midazolam bolus Dexmedetomidine at higher infusion rates Antipsychotics Propofol boluses	Morphine bolus Ketamine IV
Acute burn not mechanically ventilated	Scheduled lorazepam PO or IV or Dexmedetomidine	Scheduled morphine PO or IV	Lorazepam PO or IV	Morphine PO or IV
Chronic acute burn	Scheduled lorazepam or antipsychotics (PO)	Scheduled morphine or methadone	Lorazepam or antipsychotics (PO)	Morphine PO or oxycodone

IV, Intravenous; PO, per os (orally).

given to hemodynamically unstable patients. Dexmedetomidine has been used to provide sedation–analgesia for burned patients and to decrease opioid requirements.²⁵⁵ However, α 2 agonists have also been reported to increase excitability of heat-sensitive cutaneous nociceptors but the clinical relevance of this finding in burn patients remains unclear.²⁵⁶ The use of dexmedetomidine has recently been reported to reduce the risk of developing delirium when used for ICU sedation, especially in comparison to benzodiazepines.²⁵⁷

Anxiolytics

The recognition that anxiety can exacerbate acute pain has led to increased use of anxiolytic drugs in combination with opioid analgesics. The combination of benzodiazepines and opioids is particularly useful in premedicating patients for wound care to help reduce the anticipatory anxiety related to such procedures. Patients most likely to benefit from this combined treatment are those with either high anxiety at the time of the procedure or high baseline pain scores.²⁵⁸ The tolerance to opiates seems to be exaggerated by long-term administration of the benzodiazepine, midazolam.²⁵⁹

Gabapentin

Gabapentin is an anticonvulsant that has increasingly been used for chronic and neuropathic pain, and as an adjunct pain medication that may play a role in modulating central sensitization and hyperalgesia. Several studies have shown gabapentin to be a beneficial addition to an opioid analgesic regimen in this population.^{260,261}

Ketamine

Ketamine is a dissociative anesthetic that induces rapid and profound sedation, analgesia, and amnesia. It causes functional dissociation between the limbic and the cortical systems, producing a trance-like cataleptic state that impairs sensory recognition of painful stimuli and memory. In addition, by acting as a noncompetitive NMDA receptor antagonist, it is thought to both prevent the induction of central pain sensitization and its windup, thereby reducing the development and maintenance of opioid tolerance and hyperalgesia. Ketamine is a widely used analgesic agent in all stages of burn injury, both primarily and as an adjunct to other analgesic regimens.²⁶² Intravenous ketamine is commonly used for procedures

requiring deep sedation such as dressing changes and line placement because of its rapid onset and short duration of action, which is due to rapid redistribution. Intravenous ketamine infusions can be continued safely in the ward environment after discharge from ICU. Ketamine can also be used for long-term administration although tolerance develops with time. The other advantage is that it can be weaned rapidly without adverse consequences even after long-term use.²⁶³

Ketamine has many potential advantages for induction and maintenance of anesthesia in burn patients.²⁶⁴ Ketamine is associated with hemodynamic stability, preservation of hypoxic and hypercapnic responses, and decreasing airway resistance. Ketamine may exert beneficial antiinflammatory effects in patients with burns and or sepsis. Also, by causing peripheral vasoconstriction, ketamine may be advantageous for patients at risk for hypothermia.²⁶⁵ Whether peripheral vasoconstriction occurs in patients with major burns, and whether this causes a reduction in blood loss, is unknown. It is important that bolus doses of ketamine can cause hypotension in some patients with burn injury, despite ketamine-induced catecholamine release. This occurs because of the persistently high levels of catecholamines in these patients that result in desensitization and downregulation of β -adrenoreceptors.²⁶⁶ As a result, direct myocardial depressant effects of ketamine can manifest.

Another important feature of ketamine is that, unlike all other anesthetic agents, muscle tone and protective airway reflexes are preserved. Consequently, ketamine may be the agent of choice if one wishes to avoid manipulation of the airway (e.g., after placement of fresh facial grafts, for stent or dressing removal, for brief procedures such as dressing or line changes, or for patients with TENS).

Ketamine administration can result in a number of side effects including nausea and vomiting, hallucinations, mood alteration, bizarre dreams, and emergence delirium, which tend to occur when ketamine is used as a single agent, when given in large doses, and if administered rapidly. The administration of a benzodiazepine in combination with ketamine has been shown to decrease the frequency and severity of emergence reactions.²⁶⁷

Regional Anesthesia

Regional anesthesia can be advantageous in targeting specific aspects of burn-injury pain. In its simplest form,

regional anesthesia may be tumescent local anesthesia injected into a donor site prior to harvesting or it can take the form of subcutaneous catheter infusions, peripheral nerve blocks, or central neuraxial blockade.²⁶⁸⁻²⁷¹ While regional anesthesia can be the primary anesthetic management for surgical burn care, it is frequently also utilized as an analgesic adjunct, enabling opioid sparing and improved postoperative analgesia. Placement must take into consideration that skin donor sites and injury sites are often in different anatomic locations and that patients often have more intense postoperative pain from the split-thickness skin donor site than from the grafted burn wound.

Central neuroaxial techniques (spinals, epidurals) have been used with good effect as both primary anesthetics and postoperative adjuncts.²⁷²⁻²⁷⁴ However, fear of meningeal spread in patients densely colonized with infectious organisms, reluctance to inserting a needle through burned tissue, and anatomic surgical incompatibilities (e.g., the need to graft lower extremities but donor sites are on upper extremities or trunk) may limit their use. There are no reports suggesting epidural abscesses are more common in burn patients, but reports have suggested that intravascular catheters are more likely to become infected if placed in or near burned tissue.²⁷⁵ Administration of local anesthetics (and/or opioids) via an epidural catheter would seem to be of benefit in patients with lower extremity burns, resulting in both background and procedural analgesia, as well as autonomic sympathectomy and peripheral vasodilation.

Truncal blocks (paravertebral and transversus abdominis plane [TAP]) can be very useful to provide analgesia for donor-site harvesting, and both block techniques are also amenable to placement of catheters to extend duration of postoperative analgesia.²⁷⁶ As for central neuraxial catheters, there are theoretical concerns of increased infection with placement of a foreign body (i.e., catheter) in these patients, but such infections have not been reported. It is also likely that infection from a paravertebral or TAP catheter would be a less catastrophic event than an infection from a central neuraxial catheter (e.g., epidural abscess).

The lateral femoral cutaneous nerve is particularly well suited to block because it is exclusively a sensory nerve and innervates an area (the lateral thigh) that is frequently chosen for split-thickness skin grafts.^{277,278} Sometimes there is a need to cover the anterior and medial thigh due to the extent of skin harvest, and therefore a fascia iliaca block can also be performed.

The pharmacology of local anesthetics in burn injury patients may be altered by changes in hepatic function, protein binding, and volumes of distribution.²⁷⁹ The incidence of adverse effects of local anesthetics or tolerance does not appear altered in the burn patient, *per se*, but caution is advised in the use of these potentially neuro/cardiotoxic agents in critically ill burn patients. Recent advances in local anesthetics, such as liposomally enclosed lidocaine and bupivacaine, have the potential to offer longer duration of action with greater safety (i.e., local anesthetics stay *locally*), but studies specific to burn patients have yet to be performed.²⁸⁰

Muscle Relaxants

Muscle relaxant pharmacology is significantly and consistently altered after burn injury.²⁸¹ Exposure to succinylcholine can result in an exaggerated hyperkalemic response,

which can induce cardiac arrest. The current recommendation is to avoid succinylcholine administration in patients 48 to 72 hours after burn injury.^{282,283} An increase in the number of extrajunctional acetylcholine receptors that release potassium during depolarization with succinylcholine is the cause for increased hyperkalemia. The duration of the hyperkalemic response most likely varies with the severity of the injury and accompanying critical illness, and the extent of muscle recovery. The presence of aggravating factors such as disuse (contractures), immobilization due to long-term bed rest, inadequate nourishment, and possibly ICU myopathy may also contribute to these changes and would likely make the potential of hyperkalemia more likely.²⁸¹ Almost paralleling the hyperkalemia to succinylcholine, there is concomitantly a decreased sensitivity to the neuromuscular effects of nondepolarizing muscle relaxants (NDMRs). Resistance to NDMRs has been reported in pediatric patients 463 days after burn injury, suggesting that the hyperkalemic response to succinylcholine could also persist for more than a year.²⁸⁴ Although a hyperkalemic response to succinylcholine may be seen, whether lethal levels would be reached is unknown after such a long period. Whether small doses (0.1 mg/kg) of succinylcholine, as might be used for treatment of laryngospasm, would result in less hyperkalemia has been inadequately studied.²⁸⁵

NDMRs are the relaxants of choice in burn patients. However, the dose and duration of onset required to achieve effective paralysis can be substantially increased while the duration of paralysis is reduced. The etiology of the altered response to NDMRs is multifactorial: (1) upregulation of acetylcholine receptors, including upregulation of fetal and $\alpha 7$ (neuronal type) acetylcholine receptors at the muscle membrane; and (2) increased binding to AAG and, enhanced adrenal and hepatic elimination of the NDMRs.^{286,287} Resistance to the effects of NDMR is highly correlated with the magnitude of the burn and time after burn.²⁸⁸

Rocuronium is the drug of choice in burn patients when rapid onset of paralysis is necessary and succinylcholine is contraindicated. An increased rocuronium dose of 1.2 to 1.5 mg/kg for rapid sequence induction has been recommended in patients with major burn injury.^{289,290} It must be noted, however, that even with a dose of 1.5 mg/kg of rocuronium, the onset time to effective paralysis approximates 90 seconds in burned patients compared with less than 60 seconds in nonburned patients with a dose of 0.9 mg/kg (Fig. 87.5). Even at the higher doses, the duration of action of rocuronium can be quite variable; therefore monitoring of neuromuscular function is essential to specifically determine the dose requirement and the adequacy of reversal in patients with major burns. Preliminary evidence suggests that sugammadex, a modified cyclodextrin used for reversal of rocuronium- and vecuronium-induced nondepolarizing muscle block, can be used in burn patients, with recovery times for muscle activity similar to that in other types of patients.²⁹¹

Atracurium, broken down by organ-independent pathways (e.g., Hofmann elimination), also exhibits reduced neuromuscular effect following burns.²⁹² This suggests that the major component to resistance to NDMRs is pharmacodynamic in nature. No research study has specifically addressed the effect of cisatracurium following burn injury. However, it

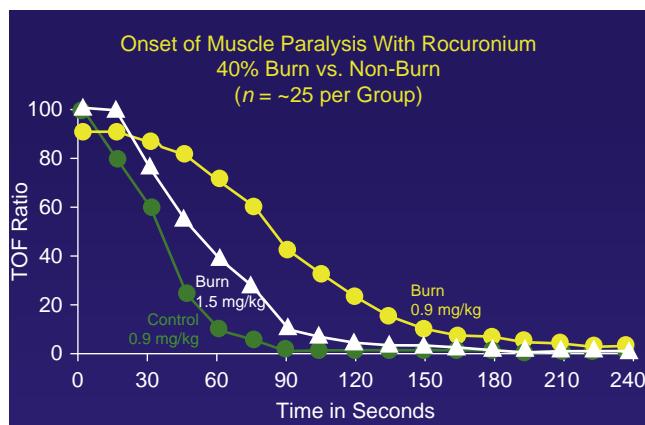


Fig. 87.5 Dose-response curves and time to maximal effect of rocuronium in adult burned and non-burned patients. Dose versus time to percent twitch suppression for rocuronium in control subjects and burned subjects of mean 40% total body surface area (TBSA) burn and studied at least 1 week after burn. In unburned patients the rocuronium dose of 0.9 mg/kg caused 95% twitch suppression in ≤ 60 seconds. The same dose has an onset of > 120 seconds following major burn. Increasing doses of rocuronium shifted dose-response curves to the left. However, even with 1.5 mg/kg dose, the onset was still > 90 seconds. TOF ratio refers to train-of-four ratio recorded in muscle during 2 Hz nerve stimulation.

can be inferred that cisatracurium may, too, have an altered pharmacodynamic profile, and dosing should be adjusted accordingly. Pharmacologic reversal of neuromuscular blockade with acetylcholine esterase inhibitors (e.g., neostigmine) poses no special problems in patients with burn injury.²⁸³ Recovery of neuromuscular blockade has been observed at serum concentrations that would cause 100% twitch depression in nonburned patients.

FLUID MANAGEMENT AND BLOOD LOSS DURING EXCISION

Intraoperative fluid administration must be carefully optimized so as not to under-resuscitate or over-resuscitate, both of which may lead to further complications in the postoperative period. Considerations for intraoperative fluid management include the magnitude of burn excision (large excisions incur more blood loss), the depth of burn (partial-thickness burn excisions involve more blood loss than full-thickness burn excisions or fascial excision), the specific hemostatic techniques used (e.g., topical or subcutaneous epinephrine), and the volume of tumescent fluid administered. Injection of tumescent fluid into the burn or donor site should be minimized in the very young as gradual absorption of the tumescent fluid several hours later can lead to pulmonary edema.²⁹⁴

Correction of intravascular volume before induction of anesthesia is essential. Good communication between the surgical and anesthesia teams and limiting the operative duration and extent of excision can prevent such problems. Blood should be readily available before extensive burn excision is initiated.

Surgical excision of burn wounds is often associated with substantial bleeding. The hyperdynamic circulation and the inflammation-induced hyperemia exaggerate the blood loss. Published estimates of the amount of blood loss during burn excision operations are in the range of 3.5% to

5% of the blood volume for every 1% TBSA excised.²⁹⁵ It is not uncommon for the surgical team to remove eschar so rapidly that the patient becomes hypovolemic and hypotensive. Increased blood loss also occurs because diffuse bleeding is used as an endpoint for excision, informing the surgeon that the tissue is viable. It is difficult to estimate blood loss during burn excision because shed blood cannot be efficiently collected in a suction canister, sponges may be presoaked with hemostatic agents, and substantial bleeding can continue unobserved beneath bulky dressings. As with the initial resuscitation, there is no single physiologic endpoint to rely on for titrating fluid replacement. Clinical judgment remains a vital component, using markers of hypoxemia, perfusion (base deficit, serum lactate), erythrocyte mass, coagulation, and pulse or arterial waveform as key assessment tools. In clinical practice, serial hemoglobin measurement in euvolemic patients is commonly used to determine the need for intraoperative transfusion. Rather than focusing on a single transfusion trigger, blood component therapy should be reserved for patients with a demonstrated physiologic need. Anticipation of continued blood loss may indicate transfusion to prevent significant anemia rather than waiting to treat it when it occurs.

Recent experience with civilian and military trauma with massive bleeding has demonstrated that mortality is decreased with an earlier and more aggressive administration of fresh-frozen plasma.²⁹⁶ Criteria for massive bleeding include loss of total blood volume in 24 hours, 4 units of packed erythrocytes transfused in an hour, or ongoing loss of more than 150 mL of blood per minute and are not unusual for patients with large burns during burn wound excision. Although clinical experience with burn patients undergoing fluid resuscitation is not exactly equivalent to hemorrhagic shock of nonburned trauma patients, it is logical to assume that more aggressive use of fresh-frozen plasma to prevent development of coagulopathy may also benefit the burn injury population who also experience massive hemorrhage. The use of platelet transfusion may also be indicated in situations with larger losses, but endpoints for such transfusions remain unclear. Targeted correction of coagulopathy using thromboelastometry may reduce transfusion requirements during surgical burn wound excision as it may indicate which blood product is needed.²⁹⁷

Surgical hemostasis should be maintained during the burn wound excision in order to limit complications, sustain hemodynamic stability, and limit the number of blood transfusions necessary. Increased transfusion requirement is associated with poorer outcomes. Several methods have been used to maintain hemostasis, including topical application or subcutaneous infiltration of the burn wound and donor sites with diluted epinephrine solutions, limb elevation and use of tourniquets for extremity surgery, use of compression dressings, and topically applied thrombin and fibrinogen. In addition, a brisk operative pace is beneficial.

TEMPERATURE MANAGEMENT

Patients with major burn injury have an impaired ability for thermoregulation and therefore require close monitoring of body temperature. The anesthetic-induced vasodilatation and surgical preparation with alcohol may aggravate the heat loss. The inflammatory response to large burns causes

an increase in the hypothalamic core temperature set point and the metabolic rate is increased to maintain this increased temperature. Hypothermia is therefore poorly tolerated as it causes an exaggerated increase in oxygen consumption and exacerbates the catabolic response to the injuries. Consequences of hypothermia during burn excisions also include decreased cardiac output, arrhythmias, abolition of hypoxic pulmonary vasoconstriction, left shift of the hemoglobin dissociation curve, interference with the normal blood coagulation mechanisms, and reduction of hepatic and renal function, as well as the reduced effect of inotropes. Intraoperative hypothermia (<36.0°C) has been associated with significantly increased blood loss, wound infection, and acute lung injury during burn surgery.^{298,299} Postoperative consequences of hypothermia include shivering, impairment of drug clearance, and masking of hypovolemia. Furthermore, shivering can dislodge grafts and increase oxygen consumption by up to 500%, resulting in increased demand on the cardiopulmonary system as well as altering nutritional needs.³⁰⁰

Maintaining body temperature in these patients is challenging. Multiple strategies are used to maintain body temperature in the operating room, including use of forced-air warming blankets, thermal water mattresses, blood/fluid warmers, minimizing skin surface exposure, and wrapping the head and extremities with plastic or thermal insulation.²⁹⁸ From an efficacy perspective, water-based mattresses, which provide convection heating, have a significant advantage.³⁰² Temperature in the operating room is commonly maintained at 80°F to 100°F (27°C-38°C), depending on the age and severity of the burn. Although a hot operating room can be uncomfortable for the operating room staff, it is often essential for maintaining the patient's temperature. The ambient temperature of the preinduction area should also be maintained at above-normal levels and patients should be covered with warm blankets during transport. Children have greater surface-area-to-body-weight ratios, resulting in more rapid heat loss.

SURGICAL CONSIDERATIONS

A general understanding of surgical management is very important for planning and perioperative management of the patient with burn injury. An appropriate surgical plan takes into account the extent, site, and depth of the burn injury; the general physical state of the patient; and the resources of the team treating the patient.³⁰³ Typically, the first excision will be undertaken within the first 72 hours after injury (early excision). Early removal of necrotic tissue in patients with major burn injury has been associated with reduced complications including decreased infection rates, improved cardiac function, decreased overall blood transfusions, reduced hypermetabolic response, and decreased overall mortality.^{304,305} However, in some cases it may be delayed until later in order to improve patient stability and/or determine how much of the burn will heal by secondary intention without need for surgery. The first excision is aimed at excision and coverage of a large portion of deep burn, and the largest areas that can be safely excised are chosen. Typically, these would be the front or back of the trunk, or large areas on the limbs. For some patients, up to 50% TBSA can be safely excised in one operation, with

significantly less blood loss and hypothermia. However, for patients with comorbidities or systemic instability, the safest course is often to carry out repeated, more modest excisions spaced a few days apart until all of the full thickness burn is excised (staged excision). The extent of excision should be planned to allow the greatest advantage of available autograft or allograft skin, so that the wound may be closed immediately after burn excision. Adequate wound closure also promotes optimal hemostasis after excision. The surgeon must continually monitor the procedure in case the patient becomes unstable and a need to abort surgery becomes evident, which requires close communication with the anesthesiologists.

The most important concept with excision of burn eschar is that debridement should be carried down to a level where only viable tissue remains. Burn wound excision can be performed as either tangential or fascial excision.³⁰³ Tangential excision removes the burn eschar in a serial fashion to a depth of viable tissue capable of accepting a skin graft, which allows for preservation of as much viable tissue as possible and usually provides a better cosmetic outcome than fascial excision. Fascial excision involves a full-thickness excision of skin and subcutaneous tissue down to the level of muscle fascia. Fascial excision is usually reserved for large, life-threatening burns where there is a need for rapid excision and is not uncommon in the older population. Advantages of fascial compared with tangential excision include its ease of dissection, less blood loss, and a well-vascularized fascial layer for skin graft placement. Disadvantages include contour deformities, permanent loss of all cutaneous sensation, and removal of lymphatics leading to lymphedema distal to the excision.

After excision or debridement of the burn wound, it is essential that the wound bed be covered since it creates a potential open portal for invasive infection. In addition, massive fluid, electrolyte, and protein loss may occur from the debrided burn wounds. Autografting is the optimal coverage; however, in massive burns either allograft or skin substitutes may be used to temporize the wound bed until autograft donor sites become available. Temporary skin substitutes provide transient physiologic wound closure giving protection from mechanical trauma, minimizing evaporative water and heat losses, and acting as a physical barrier to bacteria. These skin substitutes can also be used as a dressing on donor sites to decrease pain, enhance epithelialization, and provide temporary closure while awaiting the healing of underlying, and at times, larger injuries of widely meshed autografts. No ideal permanent skin substitute exists at present, although a number of techniques are in use, including cultured epithelial cells and dermal analogs.^{306,307}

Postoperative Care

Important postoperative considerations for burn injury patients include whether to extubate in the operating room, safe transport to the ICU, transfer of care to the ICU staff, and control of postoperative pain. A phone call to the burn unit should be made in advance before completion of the surgical procedure in the operating room to allow the care team adequate time to warm the room and to obtain necessary supplies and equipment (e.g., infusions, ventilator) that will

be needed on the patient's arrival to the burn unit. Transport of the patient to and from the operating room requires a systematic approach to optimize the patient's physiologic status safely. Monitors appropriate to the patient's physiologic status, transport oxygen with appropriate respiratory support, a plan to keep the patient warm, adequate transport staff, resuscitation drugs, and an easily available intravenous drug administration site are all necessary for safe transport. Patients requiring mechanical ventilation during transport need at least two anesthesia personnel or an anesthesia provider and another clinician to manage ventilation, observe the monitors, and administer medications during transport. Because patient agitation and extubation during transfer can be disastrous, providing adequate sedation and analgesia are essential during intrahospital transport and moving patients to or from the bed to the stretcher or to the operating table. Hypothermia during transport should be minimized.

Postoperatively, burn injury patients are likely to be less stable physiologically compared with the preoperative period. Continued bleeding may be concealed by dressings, the patient may be more prone to hypothermia, emergence may be associated with delirium, and analgesic requirements will be greater. During this period of exaggerated physiologic fragility, it is important to be especially vigilant during transfer of the monitors, and respiratory and hemodynamic support equipment to the ICU staff. Patients should recover in a prewarmed room as considerable heat loss can develop during transport. Radiant heaters, fluid warmers, and warming blankets are useful in maintaining normothermia.

The decision to extubate in the operating room depends on standard criteria with concerns specific to burn patients, including an assessment of airway patency, metabolic status, intraoperative fluid volumes, potential for ongoing bleeding, and when the patient will return for further surgery. Postoperative mechanical ventilation is generally indicated in patients with preoperative mechanical ventilation, as well as those undergoing delicate sheet grafting to the face/neck, in an effort to minimize motion and graft disruption in the initial postoperative days.

Inadequate control of pain and anxiety can adversely affect postoperative care increasing hemodynamic instability, causing asynchrony with mechanical ventilation, impairing wound healing, and negatively impacting psychological well-being. The presence of newly excised tissue and harvested donor sites are very painful. Burn-injured patients become quite tolerant of sedatives and analgesics over time, and thus doses substantially larger than normal doses may be required especially in the postoperative period.³⁰⁸ Administering intravenous bolus doses of ketamine (approximately 0.25 mg/kg) may at times work well to break through persistent pain postoperatively that seems unresponsive to opioids.³⁰⁹ The subcutaneously administered fluid and vasoconstrictors are slowly absorbed in the postoperative period and hypertension and pulmonary edema has been noted.

Pain Management

Management of burn-related pain is extremely challenging and may change in intensity and quality over time through the multiple stages of healing.³¹⁰ Background pain is most often less of a challenge compared to mobilization pain. All aspects

of burn care (e.g., dressing changes, excision and grafting procedures, physical therapy, and line insertion) are associated with pain. There can be ongoing background pain, periodic breakthrough pain, procedure-related pain, and eventually, chronic pain can develop.³¹¹ Furthermore burn-related pain is frequently undertreated in both adults and children, especially with dressing changes and wound care.^{312,313} Not uncommonly pain may occur in combination with pruritus.³¹⁴

The painful and distressing trauma of burn injury often causes fear and anxiety in patients, which can complicate their acute care and rehabilitation, and potentially contribute to increased morbidity, mortality, and length of stay. Inadequate treatment of anxiety and pain that lead to posttraumatic stress disorder has been reported to occur in up to 30% of patients with severe burn injury. Undertreated pain may also contribute to the development of chronic pain.

The mechanism of pain in burn injury patients is multifactorial and involves the inflammatory cascades and pathways that form part of the pathophysiological process following tissue damage and nerve injuries.³¹⁵ Excess production of mediators, including calcitonin gene-related peptide and substance P, and activation of NMDA receptors can cause sensitization of A-delta and C sensory nerve fibers.³¹⁶ As a result of these processes, patients may develop primary and secondary hyperalgesia, causing an altered or increased sensitivity to painful stimuli.³¹⁷ Even normal skin can develop abnormal sensitivity. Repeated tissue trauma and painful stimuli, such as during excision and grafting procedures and during frequent dressing changes, in conjunction with inflammatory processes and infection, can result in neuroplastic adaptations within the CNS, particularly leading to hyperexcitability of the dorsal horn of the spinal cord. Pain afferent sensory impulses undergo facilitation and amplification to a given stimulus, contributing to the generation and maintenance of chronic or persistent pain. Furthermore, these patients often show an altered pharmacodynamic and pharmacokinetic drug response, requiring a highly individualized pain management plan and effective management often requires multiple treatment modalities.

To provide appropriate, consistent patient comfort, standardized pain and anxiety guidelines are used in many burn centers.^{318,319} The effectiveness of the guideline-based approach to pain and anxiety is well established. These guidelines often call for a multimodal approach including the use of opioid and nonopioid analgesics, individual titration, explicit recommendations for drug selection, dosing, and increases in dosing, use of consistent, accurate, age-appropriate pain assessment tools, a limited formulary to promote staff familiarity with drugs used, and continuous reassessment of the guideline itself. Nonpharmacologic techniques may be helpful as analgesic adjuncts in reducing pain and anxiety throughout the acute and rehabilitation stages of healing. Such methods include cognitive behavioral therapy, distraction, relaxation techniques, virtual reality, and hypnosis.^{320,321}

Anesthesia providers assume an essential role in developing and refining analgesic guidelines, coordinating the multidisciplinary pain management team, and aid in the education of burn unit staff and patients. Education on pain assessment, pain control, medications, and adverse effects may take the form of consultant-led pain rounds, teaching sessions, and/or rolling training programs, which have

been shown to be effective in improving pain assessment and provision of analgesia.³²²

As burn wounds are closed, the painful stimuli decrease and the need for analgesics is gradually reduced. When a patient is being weaned, opioids and other sedative doses should be gradually decreased to prevent withdrawal symptoms and still provide adequate analgesia and anxiolysis.³²³ Patients may be safely extubated while still receiving opioid infusions. Pruritus is a common and often distressing problem for these patients during the healing process.³²⁴ It can be debilitating and interfere with sleep, activities of daily living, and may cause additional tissue damage from the scratching of healing or thin epithelium and newly grafted skin leading to increased pain.³²⁵ The causes of pruritus are multifactorial, often being triggered or worsened by opioids, heat, physical activity, and stress. Pruritus usually diminishes gradually with time but sometimes persists even after complete wound healing. A variety of approaches can control itching including systemic antihistamines, moisturizing lotions, and wearing loose-fitting clothing. Centrally acting drugs such as gabapentin and pregabalin may also be beneficial in ameliorating pruritic symptoms.³²⁶

Conclusion

Burn injury patients pose a myriad of challenges to acute and perioperative care. Despite significant advances in therapeutic strategies, such as improving resuscitation, enhancing wound coverage, appropriate infection control, and improving treatment of inhalation injury, severe burns remain a devastating injury affecting nearly every organ system and leading to significant morbidity and mortality. The decreasing incidence of burns in developed countries reduces exposure to burn-injured patients and underlines the need for ensuring adequate training in burn care by acute and perioperative providers. Anesthesiologists are often called on to care for burn injury patients through their hospitalization including acute airway management and resuscitation, intraoperative anesthetic care, intensive care, and management of postoperative pain. To optimally care for this challenging patient population requires understanding, appreciating, and anticipating the unique preoperative, intraoperative, and postoperative issues and problems of the burn injury patient that predispose them to increased morbidity and mortality.

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KEY POINTS

- Exposure to waste anesthetic gas in clinical practice is unavoidable. In the United States, the limits of exposure to waste gases are set by the National Institute for Occupational Safety and Health (NIOSH), which recommends a time-weighted average of 25 ppm for nitrous oxide and a ceiling of 2 ppm for volatile anesthetics.
- Although researchers disagree whether exposure to anesthetic gases at concentrations less than NIOSH limits affects health or performance, these limits are often exceeded. If it can be smelled, the exposure is many times greater than the safe limit.
- Occupational exposure to radiation comes primarily from x-rays scattered by the patient and surrounding equipment. A distance of 3 feet from the patient is recommended to minimize physiologic damage from occupational exposure, and a distance of 6 feet from the patient provides the same protection as 2.5 mm of lead.
- Surgical smoke is increasingly recognized as a source of potentially infectious and carcinogenic material; evacuation devices should be used where the smoke plume is created.
- Diseases can be transmitted via direct contact, droplets, or airborne particles. Some diseases are infectious only if there is direct exposure to blood or body fluid from the host. Appropriate personal protective equipment based on the suspected type of infection should always be used to prevent occupational disease transmission.
- To attenuate occupational exposure to pathogens, standard precautions at a minimum should be used at all times. The appropriate barrier precautions for intubation include eye protection, a surgical mask, and gloves.
- To prevent exposure to bloodborne pathogens, sharps safety, including the use of safety retractable needles and needleless systems, should be used.
- Occupational exposure to human immunodeficiency virus (HIV) and hepatitis B and C viruses (HBV and HCV) is most often the result of a percutaneous injury. The risk of disease transmission is generally very low but is greatest from hollow-bore needles, needles contaminated with visible blood, and exposure to a source patient with high viral titer.
- Postexposure prophylaxis (PEP) is recommended after occupational exposure to HIV or HBV. The recommended guidelines for PEP are available on the Centers for Disease Control and Prevention website. The Clinical Consultation Center PEPLine service is a free expert resource for guidance on PEP (1-888-448-4911).
- The preference for and access to potent opioids contribute to the prevalence of substance use disorder among anesthesiologists. The rate of drug-related deaths is more than twice as high in anesthesiologists as internists.
- Although many recovered anesthesiologists return to the practice of anesthesia, there is a significant relapse rate. The chance of relapse is highest in physicians who become addicted to potent narcotics early in their career. Successful recovery requires a lifelong commitment to treatment. In some cases, a change in specialty is the only solution.
- Sleep deprivation has an adverse effect on physician mood, cognitive function, reaction time, and vigilance. Although sleep deprivation and fatigue adversely affect clinical performance, the full impact on patient outcome has been difficult to determine.

The practice of anesthesiology exposes its practitioners to a variety of risks unique among medical specialties. Some of these risks are tangible or physical, such as waste anesthetic gases and communicable disease, whereas others are more insidious, such as stress, fatigue, and the risks of

substance abuse disorder. Each of these risks can be mitigated but probably not eliminated.

In the case of physical exposures such as waste anesthetic gases, radiation, and bloodborne pathogens, efficient gas scavenger systems, the use of protective lead,

needle-shielded intravenous (IV) lines, standard precautions (SP), and postexposure prophylaxis (PEP) protocols are currently commonplace in contemporary anesthesia practice. The less tangible risks are harder to reduce. Work hour restrictions may limit fatigue among housestaff; however, doing so may not improve patient outcomes, particularly when such controls do not apply to practicing physicians. Substance abuse disorders remain a problem with a multifactorial etiology and few clear solutions. This chapter examines the risks associated with each of these environmental and situational hazards, and reviews the measures one can take to avoid them.

Physical Exposures

INHALATIONAL ANESTHETICS

Volatile inhaled anesthetics are an indispensable part of anesthesia practice; however, these agents also have the potential to cause harm to patients and the physicians caring for them. Given what is suspected about their impact on patient health, vis-à-vis neurodevelopment of the very young, the spectrum of postoperative cognitive dysfunction in adults, and immunosuppressant effects on patients of all ages,¹ it is natural to wonder whether these compounds are harmful to health care workers exposed to them on a daily basis.

Definitive answers remain elusive; it is difficult to randomize exposure, and previous work suggesting a link between exposure to waste anesthetic gas and infertility and other health effects suffered serious methodologic flaws. Still, the topic of the impact of exposure on cognitive performance and health continues to generate more questions than answers.

Waste nitrous oxide (N₂O) and halogenated anesthetics in the absence of scavenging may approach concentrations as high as 3000 and 50 ppm, respectively.² This is relative to guidelines for safe practice, which historically have proposed limits of exposure well below (e.g., 25 ppm N₂O and 2 ppm of any halogenated agent).³ Although the concentration of waste gases can be well controlled with proper scavenging, in practice the levels recommended by the National Institute for Occupational Safety and Health (NIOSH) are often exceeded during the routine delivery of anesthesia.^{4,5} Although exposure to anesthetic gases is more common in pediatric anesthesia where mask inductions and uncuffed endotracheal tubes are more commonly used, the introduction of the laryngeal mask airway to anesthesia practice may increase operating room exposure to waste gases in adult cases as well. One study of inhaled induction of anesthesia and maintenance with sevoflurane and N₂O in adults resulted in violations of NIOSH standards 50% of the time.⁶

Provider Health Effects

One of the first examinations of the impact of exposure to subanesthetic concentrations of inhalational anesthetics on cognitive performance was conducted by Bruce and Bach in the 1970s. They noted that healthy volunteers in the laboratory suffered a decrease in psychomotor performance when exposed to concentrations of N₂O as low as

50 ppm, alone or in combination with 1 ppm of halothane. The same study showed that 25 ppm of N₂O combined with 0.5 ppm of halothane had no effect.^{3,7} Subsequently, three other groups of researchers studying volunteers in laboratories have been unable to confirm the earlier findings. The lack of agreement between investigators has led some to conclude "that there is no convincing evidence that anesthetics in concentrations equal to those found in unscavenged operating theatres have any effect on the psychomotor performance of healthy subjects in the laboratory."⁸ A study conducted on volunteers in an operating room during normal clinical activities in which trace concentrations of N₂O and halothane ranged from 0 to 2300 and 0 to 37 ppm, respectively, also failed to detect impairment in psychomotor performance.⁹ In contrast, a series of studies in healthy volunteers showed that subanesthetic concentrations of N₂O, isoflurane, and sevoflurane were associated with reductions in psychomotor performance, with some studies suggesting a dose-dependent effect for N₂O dose as low as 10% and a sevoflurane dose as low as 0.4%.¹⁰⁻¹² By way of comparison, 10% N₂O is equivalent to 100,000 ppm, significantly higher than the recommended safe level of exposure and the level of exposure in the Bruce and Bach studies. Whether the methods in these studies closely mimic patterns of occupational exposure in clinical practice is debatable, but it must be acknowledged, as discussed later, that occupational exposure may greatly exceed accepted safe levels.

Fetal Health Effects

Anesthetics have been implicated in the development of cancer, spontaneous abortions, and genetic and developmental anomalies. The possibility that chronic exposure to anesthetic waste gases could result in adverse health effects was first appreciated in the late 1960s, when a report of potential harm appeared in the Russian literature; Vaisman reported an increased incidence of abortions (18 spontaneous abortions in 31 pregnancies) among female anesthetists.¹³ After this initial report, a multitude of retrospective studies followed. Of these, three large studies conducted during the 1970s and 1980s in the United States and the United Kingdom all concluded that the prevalence of spontaneous abortion was substantially higher in female anesthesiologists than in female physicians working outside the operating room.¹⁴⁻¹⁷ Studies in this era also concluded that the incidence of congenital anomalies in children of male and female anesthesiologists was higher than in the control groups of physicians.¹⁸⁻²⁰ In addition to these reproductive effects, meta-analysis of six of these early studies linked the exposure to anesthetic gases to hepatic disease in male anesthesia personnel²¹ and cervical cancer, liver disease, and kidney disease in female anesthesia personnel.²² A number of studies with similar methodologies failed to detect a relationship between exposure and health.²³⁻²⁵ Although many of these older studies suffered from significant methodologic limitations,^{14,15,21} a 1997 meta-analysis of more than 19 studies completed between 1984 and 1992 reported a relative risk of abortion in female subjects exposed to anesthetic gases to be 1.48 (confidence interval [CI] 95%, 1.4-1.58).²⁶

The Task Force on Trace Anesthetic Gases was convened by the American Society of Anesthesiologists (ASA) Committee on Occupational Health of Operating Room Personnel to analyze data from all available epidemiologic studies. The methodologic flaws in the studies impaired the task force's ability to draw conclusions about an association between occupational exposure to waste anesthetic gases and adverse health effects. Their report, published in 2002,^{27,28} cited data from a prospective survey²⁹ of 11,500 U.K. female physicians documenting occupation, work practices, lifestyle, and medical and obstetric history, as well as hours of exposure and the use of scavenging equipment. This report showed the incidence of infertility, spontaneous abortion, and children with congenital abnormalities in female anesthesiologists to be the same as that in other physicians.²⁹ The position of the ASA is that "There is no evidence that trace concentrations of waste anesthetic gases cause adverse health effects to personnel working in locations where scavenging of waste anesthetic gases is carried out" and "the general conclusion... is that currently used anesthetics... have no mutagenic potential."^{27,28} This reassurance may be of little comfort in light of evidence and clinical experience that show levels of exposure in clinical practice routinely exceed those considered safe by health and regulatory agencies.^{4,5} The task force document also summarized contemporaneous recommendations from the Occupational Safety and Health Administration (OSHA) recommending that from the employee's "Right to Know," there are "potential adverse effects of exposure to waste anesthetic gases such as spontaneous abortions, and congenital abnormalities in children."^{27,28}

Subsequently, there have been several more studies that support the possibility of an intrauterine effect. An analysis of Canadian nurses identified significant odds of congenital anomalies in the offspring of nurses working in settings with exposure to waste anesthetic gases compared with those working in settings where the likelihood of exposure was lower.³⁰ Subsequent research using chromosomal and molecular DNA analysis identified correlations between exposure and genotoxic effects (e.g., sister chromatid exchanges, breaks in DNA, and chromosomal abnormalities)³¹⁻³³ but did not examine clinical outcomes in offspring. However, these more recent epidemiologic and genetic studies did not quantify exposure but rather assumed exposure by selecting health care workers from settings where exposure was assumed to have taken place.

Given the study limitations, the lack of consensus or updated ASA guidelines, and the findings that safe inhalational anesthetic levels may often be exceeded, it must be acknowledged that harm is possible. Manufacturers of anesthesia work stations, health care systems, and clinicians must remain vigilant to reduce risk.

Mitigating Health effects

The potential health effects of occupational exposure to anesthetic gas can be mitigated through waste anesthesia gas scavenging systems, establishing levels of safe exposure, auditing exposure levels, and enforcing recommended frequencies of air exchanges in locations where anesthesia gas may be found (e.g., operating rooms, procedural suites, and recovery areas).

Although the universal use of scavenging systems is critical to safe, modern anesthesia practice, it can lead to a false sense of security among operating room personnel. Kanmura and colleagues³⁴ found abnormally high ambient concentrations of N₂O in 402 delivered anesthetics, of which 42% were the result of mask ventilation, 19.2% a disconnected scavenging system, 12.5% a leak around pediatric endotracheal tubes, and 11.5% equipment leakage. Furthermore, all of the scavenging system disconnects in this study were attributed to human error rather than equipment failure.³⁴ Because most anesthesia machines were not equipped to recognize disconnected scavenging systems, a fault that has been corrected on most modern anesthesia machines, a failure of the system on older machines may not be readily apparent. Diligent maintenance and a thorough understanding of anesthesia scavenging systems are essential to comply with NIOSH standards and to minimize operating room exposure. Emerging evidence exists for the role of various activated charcoal compounds to absorb molecules of anesthetic vapor,³⁵ but these have been trialed only in experimental settings and are not yet available commercially.

Regulations and recommendations regarding workplace safety are established by several governmental agencies. The OSHA is the national agency within the U.S. Department of Labor that sets and enforces standards to ensure "safe and healthful working conditions." The Centers for Disease Control and Prevention (CDC) and NIOSH are both federal agencies conducting research and making recommendations regarding health and workplace safety. Unlike OSHA, neither the CDC nor NIOSH are regulatory agencies. State and local health departments, as well as hospital infection control departments, are also tasked with enacting and enforcing health care workplace safety standards.

The NIOSH sets recommended exposure limits for the operating room setting, stating "no worker should be exposed ... [to] concentrations greater than 2 ppm of any halogenated anesthetic or 25 ppm of N₂O" in the 1970s.³ These exposure limits have not been updated nor do they include newer volatile anesthetic drugs. These exposure levels were selected based on the lowest level known at the time to cause side effects (50 ppm N₂O or 1 ppm of halothane caused cognitive impairment in dental students)³⁶ and the level that could be easily and practically achieved.³⁷ Subsequently, it was realized that the data used to set the standards might not be generalizable because the subjects were Mormon, a subgroup likely more sensitive to depressant drugs³⁸; a more recent study with a small sample size showed cognitive impairment at 50 ppm of N₂O,³⁹ levels that are routinely found in studies^{4,5,40,41} and are well above the NIOSH levels. The threshold of perception of halothane ranges from less than 3 to more than 100 ppm.² If the anesthetic can be smelled, its concentration is likely to be many times greater than the maximum recommended level.

Occupational exposure is not limited to operating room staff, because patients continue to exhale trace amounts of N₂O for 5 to 8 hours postoperatively.⁴² Sessler and Badgwell used lapel dosimeters to measure the concentrations of volatile anesthetics of recovery room nurses during the first hour of PACU care in patients who had received inhaled anesthetics. In this study, breathing zone anesthetic

concentrations were in excess of NIOSH recommendations in 37% of patients who received isoflurane, 87% of patients who received desflurane, and 53% of patients who received N₂O.⁴³ A more recent but similar study reported a much lower average concentration (3.1 ppm) of N₂O in the breathing zone of recovering patients in a Canadian PACU,⁴² also above the recommended safe levels of exposure. These studies demonstrate the importance of proper ventilation in PACUs. Both groups reported PACU room air exchanges of 8 volumes per hour, although much of the air in the Sessler and Badgwell study was recirculated. N₂O levels can be reduced to undetectable levels with air exchanges of 20 per hour, with 25% of each exchange taken from fresh air.²⁷ Although OSHA does not currently regulate exposure to N₂O and halogenated anesthetics, the agency does provide guidelines designed to minimize workplace exposure. These include the appropriate assembly and monitoring of scavenging systems, the detection and correction of machine leaks, and the installation of effective ventilation systems.⁴⁴ In the operating room, the recommended air exchange rate is a minimum of 15 air exchanges per hour, with at least 3 air exchanges of outdoor air per hour. Laminar flow is better than turbulent flow with regard to measured levels of exposure.⁴ In the PACU, at least 6 air changes are recommended, with a minimum of 2 exchanges of outdoor air per hour. OSHA recommends air sampling for anesthetic gases be performed on a biannual basis and records of air sampling methods, locations, dates, and concentrations measured, as well as results of anesthesia machine leak tests, be maintained for at least 20 years. Although OSHA is a government agency, these recommendations are not legally mandated.^{27,28}

In summary, the possibility that waste anesthetic gas at levels routinely encountered in clinical practice could cause deficits in performance and human health remains. Caution must be exercised, and clinicians should limit their exposure as much as possible.

RADIATION

The anesthesiologist is routinely exposed to both ionizing and nonionizing electromagnetic radiation. The former is primarily from x-rays and occasionally from radioactive isotopes that release gamma rays, and the latter is from lasers. Less common is contact with ionizing radiation from radioactive isotopes that release either alpha or beta particles. Ionizing radiation has enough energy to create both free radicals and ionized molecules in tissues by driving electrons completely out of their stable orbitals. If the radiation exposure is severe enough, tissues may be destroyed or chromosomal changes may cause malignant growth. Nonionizing radiation may excite electrons to move from the ground state to higher orbitals in molecules, but the electrons remain in the molecule. In this case, damage to tissues may result from the heat produced by the absorbed radiation.

Ionizing Radiation: X-rays

In the past, exposure to radiation occurred mostly in the operating room with the use of portable fluoroscopy and x-ray machines. Advancements in endovascular surgery, hybrid cardiac surgery procedures, electrophysiology

TABLE 88.1 Relevant Exposure Limitations for X-Rays

Region	OSHA*		ICRP†	
	rem	mSv	rem	mSv
Head, eyes, gonads	5	50	2	20
Hands, wrists	75	750	50	500
Skin of the whole body	30	300	50	500
Pregnancy	0.5	5	0.1	1

*Occupational Safety and Health Administration.⁴⁷

†International Commission on Radiological Protection.⁴⁸

studies, and other imaging procedures significantly increase exposure of anesthesia personnel to ionizing radiation⁴⁵ relative to traditional operating room cases. Radiation is undetectable with our normal senses, so a basic understanding of its features will minimize exposure.

One Sievert (Sv) is equal to 100 rem and is a measure of the biologic damage from radiation adjusted to apply to all tissues.⁴⁶ Estimates of radiation exposure from natural sources vary, depending on geographic location. The average in the United States ranges from 0.8 to 2 mSv (80-200 millirem [mrem]) per year. Natural radiation comes primarily from cosmic rays (approximately 0.4 mSv at sea level, with an increase of 0.1 mSv/1000 feet), as well as from radioactive compounds found in soil, brick, and concrete. For most physicians, the additional radiation from occupational exposure is no greater than that from natural sources. OSHA sets limits of occupational exposure (expressed as rem) that vary by body area; allowable limits are higher for the hands than for the whole body, gonads, or blood-forming parts of the body.⁴⁷ An easy rule of thumb is 5 rem (50 mSv) per year, with no more than 1.25 rem (12.5 mSv) in any given calendar quarter. In 2007 the International Commission on Radiological Protection, an international nonprofit, proposed more stringent limits than those proposed by OSHA (Table 88.1), and both agree that limits should be lower for personnel who are pregnant.^{48,49}

Occupational exposure to radiation comes primarily from x-rays scattered by the patient and the surrounding equipment, rather than directly from the x-ray generator itself.⁵⁰ One chest radiograph results in approximately 25 mrem of exposure to the patient; procedures requiring multiple films occasionally involve more than 1 rem. The amount of radiation generated during fluoroscopy depends on how long the x-ray beam is on; just as light is reflected from surfaces, x-rays are reflected from the surfaces on which they impinge. This scattering accounts for most occupational exposure. Research findings vary about the degree of exposure typical for anesthesia providers, but most studies show low levels of exposure.^{45,51-53} Recent studies have compared risk profiles of various positions of the anesthetist and the x-ray beam. A simulation-based study using phantom patient and anesthetist models with dosimeters demonstrated that exposure was greater near the head of the bed (vs. along the sides of the bed) or when the x-ray beam was in either of the lateral positions (e.g., shooting cross-table images).⁵⁴ A real-time evaluation of exposure in personnel conducting transesophageal echocardiography (TEE) during transcatheter aortic valve replacement showed that the TEE operator receives 5 times as much radiation as other

clinicians involved in the procedure.⁵⁵ Furthermore, this exposure is heightened by the use of oblique angles for imaging. Notably, by using additional shielding (e.g., a ceiling-mounted lead acrylic shield), this exposure was reduced by more than 80%.

Mitigating Health Effects

Radiation physicists recommend the “As Low As Reasonably Achievable” guiding principle for radiation exposure to both the patient and practitioner. Technologic innovation leading to advances in imaging technology and industrial design may further limit exposure.^{56,57}

Because the intensity of scattered radiation is inversely proportional to the square of the distance from the source, the best protection is physical separation. A distance of at least 3 feet from the patient is recommended. Six feet of air provides protection the equivalent of 9 inches of concrete or 2.5 mm of lead.⁵⁸ Using studies of real-time dosimeters and simulation studies using phantom patients, a recent systematic review found that at a 4.9-foot (1.5 m) distance from the x-ray source, exposure was no greater than that due to background radiation.⁵¹ This finding has been replicated in a handful of studies of clinical exposures.^{45,52} The authors go so far as to question the need for anesthesia personnel to wear lead aprons, which conflicts with OSHA recommendations.⁵⁹ Although they may be uncomfortable, aprons containing the equivalent of 0.25 to 0.5 mm of lead sheet are effective in blocking most scattered radiation and such devices are recommended to be worn whenever there is an exposure risk.⁶⁰ Uncovered areas, such as the lens of the eye, still bear the risk of injury,⁵⁰ and radiation dose to the eyes varies with the type of surgery and the position of the anesthesiologist relative to the patient and x-ray field.^{54,61} OSHA recommends opaque goggles for health care workers in the “direct x-ray field.”⁵⁹

Nonionizing Radiation: Lasers

Laser is an acronym for light amplification by stimulated emission of radiation. Lasers produce infrared, visible, or ultraviolet light. A surgical laser produces intense, focused electromagnetic radiation to cut or destroy tissues. Although the radiation from lasers is nonionizing, it is potentially unsafe both because of its intensity and because of the matter released from tissues during treatment.

Of those in common clinical use, carbon dioxide and neodymium:yttrium-aluminum-garnet (Nd:YAG) lasers emit light in the far-infrared and near-infrared wavelengths, respectively; argon and tunable dye lasers produce visible light.⁶²

Eye injuries are the greatest risk to personnel working near lasers. Strict standards for protection have been developed based on current understanding but are subject to periodic revision. Either direct exposure or reflected radiation may cause eye damage. Injuries include corneal and retinal burns, destruction of the macula or optic nerve, and cataract formation. Protective eyewear is designed to filter out the radiation produced by a specific type of laser while still permitting vision. For example, clear plastic lenses block the far-infrared (10,600 nm) radiation from carbon dioxide lasers but provide no protection against the near-infrared (1064 nm) radiation emitted by Nd:YAG lasers. The type of protection provided by a given filter is marked on the

frame of the goggles and should be checked before use. Filters that are scratched should not be used. Because certain filters block portions of the visible spectrum, it is prudent to confirm preoperatively that patient monitors can be seen and interpreted correctly with goggles in place. Protective eyewear is recommended for all exposed personnel because reflected radiation can be as hazardous as direct radiation and, unlike x-ray radiation, the intensity is not diminished significantly by the distance traveled in the average operating room.⁶²

In addition to direct injury from laser light, clinicians should avoid the smoke plume created by lasers.⁶³⁻⁶⁵ Under experimental conditions, viable bacteria have been recovered from the plume emanating from laser irradiation,⁶⁶ as have compounds known to be carcinogens and environmental toxins.⁶³ Intact DNA from human papillomavirus (HPV) has been detected in the vapor from both laser-treated plantar warts and genital condylomata^{67,68} and on the gloves of treating physicians.⁶⁹ Human immunodeficiency virus (HIV) proviral DNA has been found in laser smoke produced by vaporizing cultures of HIV-positive cells.⁷⁰ Although these experiments, which used tissue cultures, do not replicate routine clinical circumstances, they stress the importance of strict attention to smoke removal. Simulation studies confirm that concentrations of laser-generated particulate matter are higher near the operating field than elsewhere in the room, sometimes by a factor of four, regardless of the degree of room ventilation.⁶⁴

As an extreme example, a case report documented the appearance of laryngeal papillomas in a laser surgeon who had previously treated several patients infected with anal condylomata without the benefit of a laser smoke evacuator.⁷¹ Tissue from the surgeon’s laryngeal tumors contained HPV DNA types 6 and 11, the same viral types that are commonly harbored by anogenital condylomata. Hence it is prudent to scavenge all vaporized debris.

SURGICAL SMOKE

Increasing attention is focused on the health effects of exposure to surgical smoke created by electrocautery and ultrasonic scalpels.⁷² Data suggest that smoke from electrocautery contains infectious and malignant cells, albeit in small quantities, as well as carcinogenic compounds.⁷³ Ultrasonic scalpels can produce viable cells in the smoke plume, as demonstrated in a study that showed that the malignant cells grew cancer when subsequently injected into mice.⁷⁴

Data from a NIOSH survey of health care workers shows that the majority of operating room personnel believe local exhaust ventilation devices (e.g., smoke evacuators on the surgical field) are not routinely in use.⁷⁵ Respondents reported that a lack of institutional protocols and a belief that exposure was minimal or not concerning were responsible for the lack of such protective strategies. Anesthesia personnel are intimately familiar with the various odors common in our practice; the smell of flesh burned with electrocautery should be a signal to those in the operating room that they are being exposed to potentially harmful material.

Mitigating the effects of exposure to surgical smoke is a critical endeavor. Most standard surgical masks trap only the largest of the smoke particles,⁷⁶ and standard surgical masks are demonstrably ineffective at filtering particles generated

TABLE 88.2 Occupational Exposure, Risks, and Safety Measures

Exposure	Sources	Potential Risks	Protection
Inhalational agents	Free gases Mask inductions Use of LMA Agent spill Inadequate scavenging	Infertility Decrease in psychomotor performance Cancer development Spontaneous abortion Hepatic disease Congenital abnormalities	Scavenging systems Air exchange Use mask induction appropriately Activated charcoal filters
Ionizing radiation	Portable fluoroscopy Hybrid operating rooms Interventional suites	Cancer Eye damage Infertility	Distance >3 feet from source Lead aprons Lead shields Lead surgical caps Periodic radiation monitoring
Nonionizing radiation	LASER	Eye injury Vaporization of bacterial or viral matter	Protective eyewear Laser-specific surgical masks
Microdebris from smoke	Surgical cautery Ultrasonic scalpel	Exposure to bacterial, viral, and carcinogenic matter	Surgical smoke evacuators FFP 2 particulate masks

by laser.^{77,78} Even laser-specific masks were many-fold less effective at particle removal than the comparator, a protection class FFP level 2 dust and fine particle mask.⁷⁷ The median size of particles in plume samples obtained intraoperatively is 0.31 μm in diameter (range, 0.1-0.8 μm). Even after filtration of particles greater than 0.5 μm in diameter, exhaust smoke from tissues treated with a carbon dioxide laser causes pulmonary lesions in laboratory animals. If all particles larger than 0.1 μm are scavenged, no lung damage occurs, emphasizing the importance of scrupulous removal of the plume,^{70,79} a practice advocated by the CDC, OSHA, and the Association of Perioperative Registered Nurses.

By using adequate evacuation and filtration equipment specifically designed to scavenge such vapors, it may be less likely that operating room personnel will be contaminated by laser-dispersed HPV DNA.⁶⁷ However, laser-specific surgical masks should also be used whenever lasers are in use, and institutions should evaluate the use of smoke evacuators for the surgical field (Table 88.2).

Infectious Exposures

Understanding the basic principles of infection control is essential to the safe and responsible practice of anesthesia.

INFECTION PRECAUTIONS

Infection control standards have changed dramatically over the past 50 years, with the introduction of protocols for handwashing, use of personal protective equipment (PPE), incorporation of environmental controls, and implementation of sharp safety devices.

Beginning in 1985 in response to the HIV/AIDS epidemic, the CDC released recommendations for “universal precautions” to be used by all health care workers exposed to blood or body fluids, regardless of the infectious status of a patient.⁸⁰ These recommendations were expanded in 1996 into the concept of standard precautions (SP), which are to be used with all patients at all times. The CDC also introduced airborne, droplet, and contact transmission-based precaution guidelines for diseases spread by those specific routes.⁸⁰

Standard Precautions

SP encompass hand hygiene between every patient contact event, before aseptic tasks, and after contact with bodily fluids. Hand hygiene includes both the use of plain or antibacterial soap and water and the use of alcohol-based gels without water. Unless hands are visibly soiled, hand hygiene with an alcohol-based gel has greater antimicrobial effect and is preferred to soap and water.⁸¹ It is estimated that every anesthesia procedure presents at least 25 hand hygiene opportunities and hundreds of contact events with the patient and then surfaces in the anesthesia environment but that anesthesiologists are compliant with hand hygiene recommendations only approximately 1% to 10% of the time.^{82,83} Importantly, using gloves does not obviate the need for hand hygiene, because 1% to 2% of examination gloves have microperforations that can allow bacteria to penetrate the glove surface.⁸⁴

SP include the application of PPE such as a gown, gloves, a mask, or eye protection as appropriate during patient-care activities likely to expose a health care worker to a patient’s blood or secretions. The need for PPE differs depending on the specific task at hand. During intubation, it is recommended that the anesthesiologist perform hand hygiene and use gloves, a mask, and eye protection.⁸⁵ One study estimated the frequency of glove use by anesthesiologists during intubation, extubation, and IV line placement at only 10% for attending anesthesiologists and 50% for trainees.⁸⁶

When a patient is known or suspected to have an infection transmitted by a specific route, such as contact, airborne particles, or droplets, specific transmission-based precautions should be used in addition to SP. These precautions are discussed in more detail later.

When transporting a patient on transmission-based precautions, it is important to ensure that the infectious areas of the patient are appropriately contained. For example, if a patient is on airborne precautions for active TB, then the patient should wear an N95 mask or higher during transport. If a patient is on contact precautions, the patient should be covered in a gown or sheets and providers should wear clean PPE during transport.⁸⁰

TABLE 88.3 Immunizations Recommended for Health Care Workers

Infection	Risk to Health Care Workers	Immunization	Special Considerations
Hepatitis B	Percutaneous or mucosal exposure to infectious blood/body fluid	3-dose series at 0, 1, and 6 months	Approximately 1% receiving the complete series will not have full immunity
Influenza	Infectious transmission via droplet route	Yearly	Effectiveness of vaccine varies with year
Measles, mumps, rubella	Infectious transmission through droplet and airborne routes	2-dose vaccine for measles, mumps and rubella together (usually as a child)	1% of health care workers who were vaccinated may have lost immunity
Pertussis	Contact or droplet transmission	Every 10 years (usually as Tdap with tetanus and diphtheria toxoids)	Even immunized health care workers need postexposure prophylaxis
Varicella	Contact or airborne transmission	2-dose series (not needed if history of past varicella infection)	

Information from Immunization of health-care personnel, recommendations of the Advisory Committee on Immunization Practices (ACIP), Centers for Disease Control and Prevention 2011- REF 20.

Environmental Controls

Environmental controls are additional safety measures used to prevent the spread of airborne infectious particles; examples in hospitals include engineering systems to manage ventilation (e.g., negative pressure rooms), use of high-efficiency particulate air (HEPA) filtration, frequent air exchange rates, and ultraviolet irradiation of air in the upper portion of a room or in air ducts.^{87,88} Because operating rooms are kept at positive pressure with respect to hallways (to prevent the introduction of infectious particles into a sterile area), elective procedures on patients with active TB or other airborne diseases should be postponed. If it is not possible to delay surgery, the procedure should be performed in an operating room with an anteroom.⁸⁹ A HEPA filter should be placed in the circuit after the Y-connector, to prevent contamination of the anesthesia machine.

Needlestick and Sharps Safety

A key element of universal precautions and SP is the prevention of injuries due to sharps and the use of safe injection practices. In 2000 the CDC estimated that health care workers experience more than 600,000 needlestick and other percutaneous injuries yearly.⁹⁰ OSHA has developed standards to protect health care workers from exposure to bloodborne pathogens. These standards were most recently updated in 2001 after the passage of the federal Needlestick Safety and Prevention Act of 2000.⁹¹ OSHA standards mandate that employers make available safety-engineered sharps devices, provide for safe disposal of sharps, make appropriate PPE available, offer free hepatitis B virus (HBV) vaccination to workers who have been exposed to potentially infectious fluids, and have procedures for medical evaluation and PEP for employees exposed to bloodborne pathogens.⁹² With the implementation of safety-engineered sharps, overall needlestick injury rates have dropped significantly from before 2000 to after 2004, in some studies, by well over 50%.⁹³

The risk of a sharps injury correlates with medical specialty and clinical experience. The Duke Health and Safety Surveillance System Study quantified the risk of percutaneous exposures to body fluids by various health care worker groups. In this study, anesthesia residents had 19 needlestick events per 100 residents per year, compared with an exposure rate for all anesthesia providers of 6.9 events per 100 employees per year and an overall exposure rate of 3.9 events per 100 full-time employees.⁹⁴ In addition, night

work and shifts lasting greater than 24 hours were associated with an increased rate of needlestick injury.⁹⁵

Injuries from the use of hollow-bore needles account for more than half of sharps injuries.⁹⁰ Percutaneous injuries can occur during and after use of a sharp device. Wearing gloves, double gloving, and avoiding recapping needles by using a two-handed technique can reduce the risk of a needlestick injury.^{90,96} In addition, the use of a curved suture needle with a needle holder for suturing is safer than the use of a handheld straight suture needle.⁹⁷

Accidental needlesticks are underreported. The CDC estimates that only approximately 54% of percutaneous exposures are reported to occupational health, perhaps because of fears that reporting will be time consuming or nonconfidential.⁹⁸ All occupational needlesticks and exposures should be reported to a hospital occupational health program for evaluation, testing, and possible PEP.

Vaccine Preventable Illness

The CDC Advisory Committee on Immunization Practices recommends that all health care providers be vaccinated against a variety of vaccine-preventable diseases to reduce the risk of occupational exposure and transmission of these pathogens (Table 88.3).

The most up-to-date infection control guidelines are available at the CDC website.⁹⁹ Recommendations for infection control specific to the practice of anesthesia have been published by the ASA Committee on Occupational Health Task Force on Infection Control.⁶

TRANSMISSION OF INFECTIOUS AGENTS

Anesthesia providers are exposed to a wide range of infectious pathogens, including bacteria, viruses, fungi, parasites, and prions. The three principle routes of pathogen transmission are via contact, droplet, and airborne spread. Bloodborne infectious agents, such as HIV and HBV, are transmitted to the health care worker via percutaneous injuries or direct contact of nonintact skin or mucous membranes with infected blood or other serum derived body fluids (Table 88.4).^{100,101}

Contact Transmission

Contact transmission, the most common type of infectious transmission,⁸⁰ can either be direct, from an infected person to another person, or indirect, with a contaminated

TABLE 88.4 Infectious Precautions for Selected Transmissible Diseases*

Infection	Type of Infectious Precaution	Special Considerations
AIDS/HIV	Standard	Standard precautions include needlestick safety. Postexposure prophylaxis indicated for some exposures
Aspergillosis	Standard	
<i>Clostridium difficile</i>	Contact	Handwashing is required after patient contact, spores are not removed with alcohol-based gels
Ectoparasites (i.e., lice, scabies)	Contact	
Gastroenteritis	Standard	Contact precautions if rotavirus, or if the patient is diapered or incontinent
Hepatitis (A-E)	Standard	Postexposure prophylaxis may be indicated for HBV percutaneous exposure
Herpes simplex	Contact	Until lesions are dry and crusted
Severe primary mucocutaneous	Standard	
All other infections (including encephalitis)		
Herpes zoster (Varicella-zoster)	Standard Local Disseminated	Airborne, Contact Nonimmunized health care workers should not enter room if immunized caregivers are available.
Influenza	Droplet	Postexposure prophylaxis may be indicated in some circumstances
Measles	Airborne	Nonimmunized health care workers should not enter room if immunized caregivers are available.
Meningococcal disease	Droplet	Postexposure prophylaxis may be indicated in some circumstances
Mumps	Droplet	Nonimmunized health care workers should not enter room if immunized caregivers are available.
Multidrug resistant organisms (including MRSA, VRE, ESBLs)	Standard or Contact	Contact precautions are recommended in settings with evidence of ongoing transmission, acute care settings, or wounds that cannot be contained by dressings
Pertussis	Droplet	Postexposure prophylaxis may be indicated in some circumstances
Prion diseases	Standard	Use special sterilization procedures for contaminated surgical equipment
Respiratory syncytial virus	Contact	Use mask for actively coughing patient according to standard precautions
Rhinovirus	Droplet	
Rubella	Droplet	Nonimmunized health care workers should not enter room if immunized caregivers are available.
Severe acute respiratory syndrome (SARS)	Airborne, Droplet, Contact	
Staphylococcus (excluding MRSA)	Contact	
Major draining wounds	Standard	
Minor wounds or infections		
Streptococcus (group A)	Droplet Contact-only for major wounds	Droplet if major infectious, involves the respiratory tract. Standard precautions if a minor or limited infection
Tuberculosis (active)	Airborne	Contact if active draining lesions present
Pulmonary	Airborne, Contact*	
Extrapulmonary		
Viral hemorrhagic fevers (including Ebola, Marburg, Lassa)	Droplet, Contact, and Airborne	

*Excerpted from Appendix A. Type and duration of precautions recommended for selected infections and conditions. Centers for Disease Control and Prevention (CDC) 2007 guideline for isolation precautions: preventing transmission of infectious agents in health care settings.⁸⁰
HBV, Hepatitis B virus; MRSA, methicillin-resistant *Staphylococcus aureus*.

intermediate such as a laryngoscope handle in an operating room.¹⁰² When a patient has a contact-transmitted infection, contact precautions should be used at all times. These include keeping patients separated at least 3 feet from neighbors and wearing a gown and gloves for all patient-care interactions. Examples of microorganisms commonly transmitted via contact include respiratory syncytial virus,

herpes simplex virus, *Staphylococcus aureus* (including methicillin-resistant *S. aureus*), and scabies.⁸⁰

Clostridium difficile is an epidemiologically important contact-transmitted organism in health care facilities. *C. difficile* is a gram-positive spore-forming anaerobe that causes diarrhea and pseudomembranous colitis. The use of broad-spectrum antibiotics such as cephalosporins, clindamycin,

and vancomycin are associated with *C. difficile* infection. Notably, *C. difficile* spores are not removed by the use of alcohol-based hand disinfectants. Health care workers who are in contact with patients suspected of having *C. difficile* infection should use contact precautions at all times and wash hands with soap and water after patient contact.⁸⁰

Norovirus, a single-stranded RNA virus, is an important contact-transmitted organism and the most common cause of acute gastroenteritis in health care settings.¹⁰³ Health care workers should use standard and contact precautions any time a patient presents with diarrheal symptoms. Health care workers who contract norovirus should check with their institutional policy, which may require that the worker be excluded from work for at least 24 hours after symptoms have resolved.¹⁰³

Parasitic skin diseases caused by lice and scabies are also spread via contact transmission. Anesthesiologists should be aware of the highly contagious nature of these conditions and use a gown and gloves for all interactions with patients who have an undiagnosed rash or are suspected of carrying ectoparasites. PEP is not routinely recommended.¹⁰⁴

Droplet Transmission

Droplet transmission occurs when an infectious agent travels a short distance directly from the respiratory tract of an infected source to a susceptible mucosal surface in a recipient.⁸⁰ Droplet transmission can occur during intubation, airway suctioning, or if the patient coughs or sneezes.¹⁰⁵ The risk of droplet transmission is believed to be greatest at a distance of less than 3 feet from an infected person. For this reason, appropriate PPE precautions for patients with droplet-transmitted infections include keeping patients separated at least 3 feet from neighbors and wearing a mask for all close patient contact.

Microorganisms commonly transmitted via droplets include influenza and other respiratory viruses, group A streptococcus, and *Neisseria meningitidis*.⁸⁰

Influenza virus types A and B cause respiratory illness in humans, ranging from mild to severe disease (influenza A infection generally causes more severe disease). Subtypes of influenza A virus are named for the surface antigens they display: H (hemagglutinin) and N (neuraminidase). Because these surface antigens change over time (termed antigenic drift), protective immunity from prior exposure to the influenza virus is partially lost. More infrequently, the surface antigens can change significantly (antigenic shift) and cause pandemic disease because the population has no immunity against the new virus strain. A pandemic H1N1 influenza A strain in 2009 caused illness in an estimated 60 million Americans.¹⁰⁶

Because influenza virus subtypes change yearly, the CDC recommends that all persons older than 6 months be vaccinated yearly.¹⁰⁷ The influenza vaccine cannot cause influenza infection.¹⁰⁷ Anesthesiologists are at particular risk for exposure to influenza because of close contact with nasopharyngeal secretions. Increasingly, health care organizations are making yearly flu vaccination a mandatory condition of medical credentialing.¹⁰⁸

Pertussis, a respiratory illness caused by *Bordetella pertussis*, and invasive meningococcal infections caused by *N. meningitidis* are two droplet-transmitted infections for which PEP is recommended for exposed health care workers.^{80,105}

Because intubation and suctioning are considered high-risk exposures to these infections, even vaccinated anesthesiologists should be aware of the need for chemoprophylaxis if they are involved in the care of infected patients.²⁴ The CDC recommends 5 to 7 days of macrolide therapy for pertussis exposure and single-dose oral ciprofloxacin or intramuscular ceftriaxone for exposure to invasive meningococcal disease.^{109,110}

Droplet transmission of oral flora from health care workers to patients during lumbar puncture where the provider was not wearing a face mask has been implicated as a cause of bacterial meningitis.^{80,111-113} Anesthesia providers should wear face masks when placing invasive catheters or needles, including into the spinal, epidural, or central venous spaces to reduce the risk of droplet transmission of infectious agents.

Airborne Transmission

Airborne transmission occurs when infectious particles are carried in the air and remain infective over time and distance, such as when infected droplets dry into much smaller particles called droplet nuclei or when small infectious particles (i.e., spores) are created. These small (<5 µm particles) are more likely to travel into the lower respiratory tract and cause severe infection. Patients with suspected airborne infections should be placed in a negative pressure rooms with specific air filtration requirements. All health care workers taking care of patients on airborne precautions should wear N95 or higher-level respirators.^{80,87} These respirators must filter particles of 0.3 µm or greater in size with at least 95% efficiency. A tight mask fit is essential to proper mask function, and for this reason employers are required to perform respirator mask fit testing during employee training and periodically thereafter.⁸⁸

Microorganisms transmitted via the airborne route include *Mycobacterium tuberculosis* (TB), rubeola virus (causing measles), and varicella-zoster virus (causing chicken pox).⁸⁰

TB is the result of infection with *M. tuberculosis*, an acid-fast bacillus that has caused disease in humans for more than 4000 years. Infection with *M. tuberculosis* occurs when a person inhales small infected airborne particles containing the bacterium. These particles, called droplet nuclei, are 1 to 5 µm in size and can remain airborne for prolonged periods, spreading throughout a room or building.⁸⁸ The risk of infection with *M. tuberculosis* varies with proximity to a source and duration of exposure. Anesthesiologists are at particularly high risk for TB exposure because bronchoscopy and endotracheal intubation have been reported as the two highest-risk procedures leading to skin test conversion in health sector workers.^{89,114}

In otherwise healthy individuals who have been infected with *M. tuberculosis*, the disease is usually contained by the immune system in 2 to 12 weeks, when immunologic tests for TB will become positive,⁸⁸ although the bacteria can remain in the body for years, a condition referred to as latent TB. Latent TB is asymptomatic and is not infectious. Five to 10% of people who are infected with *M. tuberculosis* go on to develop active TB over the course of their lifetime.¹¹⁵ The risk of developing active TB after infection with *M. tuberculosis* is much higher in those with a compromised immune system, such as persons with HIV or diabetes or undergoing

immunosuppressive therapy.⁸⁸ Although most TB is curable if properly treated, untreated TB can lead to death in more than 50% of cases within 5 years.³⁵ Currently, the World Health Organization estimates that 1.7 billion people, approximately one-fourth of the world's population, are infected with *M. tuberculosis*.¹¹⁵ Ninety-five percent of TB cases and deaths occur in developing countries.

In the United States, there were 9287 new cases of TB reported in 2016, with an incidence of 2.9 cases per 100,000 persons.¹¹⁶ The incidence of TB in the United States has been declining after a surge in the 1990s, related to infection control measures put in place by the CDC.⁸⁸ All health care settings must have a TB infection-control program to identify and treat persons with TB, educate and screen health care workers at risk for contracting TB, develop environmental controls such as isolation rooms and negative pressure ventilation systems, and implement respiratory protection programs to reduce health care worker exposure risk.⁸⁸

The commonly used tuberculin skin test (purified protein derivative) provides a qualitative measure of TB exposure. A newer quantitative test for TB is available that can test for atypical organisms but requires a blood sample.⁸⁸ All health care workers at high risk for exposure to TB should be skin tested at the time of employment and retested annually for a new exposure. A two-step test is recommended for anyone who tests negative more than 1 year after a prior test or TB exposure because latent TB infections can result in initial false-negative results from waning of the delayed type hypersensitivity response. The first test will "boost" the response, leading to a positive result with the second test in those with a true exposure.⁸⁸

Health care workers who have a newly positive tuberculin skin test need to be screened for active TB with a clinical evaluation and a chest radiograph. If active TB is diagnosed, treatment according to recommended guidelines should begin immediately. Disease reporting laws generally require notification of local or state health departments within 24 hours of an active TB diagnosis. If active disease is excluded, drug therapy for latent TB infection is recommended for health care workers, in consultation with occupational health and infectious disease physicians. Standard drug regimens for treatment of latent TB are 6 to 9 months of isoniazid or 4 months of rifampin.⁸⁸ Those with a previous history of liver injury may not be good candidates for treatment of latent TB infection. Latent TB is not infectious, even if untreated, and should not preclude the anesthesiologist from engaging in patient care.

Complex Transmission

Microorganisms are commonly transmitted by more than just one route. For example, respiratory syncytial virus is most commonly transmitted via contact but can also be transmitted via droplets,^{80,117} necessitating health care workers to use PPE to guard against both forms of transmission. Therapies commonly used for respiratory support, such as noninvasive positive pressure ventilation, have been implicated in the aerosol dispersion of respiratory diseases such as influenza.

Aerosol dispersion of infectious particles normally transmitted via droplet or contact transmission was a hallmark of the severe acute respiratory syndrome (SARS) viral outbreak

TABLE 88.5 Bloodborne Pathogens

	Risk of Seroconversion After Percutaneous Exposure*	Progression to Chronic Disease
Hepatitis B	6-30%**	5% of immunocompetent adults
Hepatitis C	0.5-2%	75-85%
HIV	0.3%	100%

*Risk varies depending on type of exposure and infectivity of the host.

**In those without serologic immunity.

Risks of seroconversion are related to: depth of exposure, viral load of patient, type of exposure (hollow-bore needle highest risk), presence of visible blood on the needle.

that occurred between 2003 and 2004. SARS was a respiratory disease with a reported 6% mortality rate.⁸⁰ In some centers, up to 50% of the cases of SARS were in health care workers who had cared for patients with SARS.²⁵ Endotracheal intubation, tracheal suctioning, and care for patients on noninvasive positive pressure ventilation were identified as risk factors for health care worker infection.^{80,105,118}

Bloodborne Organisms

Anesthesiologists are at constant risk of needlestick or other sharps injuries or injuries where blood or other serum-derived fluids from a patient could come in contact with nonintact skin or mucosal surfaces. The risk that accidental exposure to blood or body fluids will result in infectious transmission varies with the type of exposure (percutaneous being the highest risk), the instrument of exposure (hollow bore needles are higher risk than suture needles), the depth of needle penetration, the infectious agent, and the quantity of infectious particles a health care worker is exposed to. After an occupational exposure, the area should be washed with soap and water. Use of antiseptics or attempting to express fluid from the wound site has not been shown to be effective at reducing the rate of infectious transmission.¹¹⁹ PEP may be recommended to reduce the risk of seroconversion. HBV, hepatitis C virus (HCV), and HIV are the three bloodborne infectious agents that pose the greatest occupational risk to the anesthesiologist (Table 88.5).⁸⁵

HBV is a cause of acute viral hepatitis that is acquired by percutaneous or mucosal contact with infected blood or body fluids. Importantly, HBV can survive outside of the body for up to 7 days, and even needles without any visible blood can be infectious.^{119,120} In unvaccinated individuals, the risk of seroconversion after percutaneous exposure to HBV varies from 6% to 30%, depending on the infectivity of the source and the type of contact with serum.^{121,122} More than 50% of acute infections are asymptomatic, but signs of acute infection include fever, jaundice, fatigue, and abdominal pain. Rarely, acute HBV infection can lead to fulminant hepatitis. In adults, the virus is cleared completely after initial infection in up to 95% of cases.¹²⁰ However, chronic HBV can cause cirrhosis and hepatocellular carcinoma. Liver disease is the cause of death in 25% of those chronically infected with HBV.¹²⁰

In the United States, there are approximately 20,000 new cases of HBV infection per year and an estimated 850,000 to 2.2 million people living with chronic hepatitis B infection.¹²³ Globally, there are nearly 900,000 HBV-related

deaths every year. Before the introduction of a hepatitis B vaccine in the 1980s, HBV was a significant occupational hazard for anesthesiologists. One multicenter study of anesthesia residents in the 1980s found that 17.8% of 267 tested residents showed serologic evidence of exposure to HBV.¹²⁴ The availability of a vaccine has dramatically changed the epidemiology and occupational risk of HBV. The number of HBV infections in health care workers declined by 98% between 1982 and 2010.¹¹⁹

Health care workers are strongly encouraged to complete a series of three injections of hepatitis B vaccine. OSHA requires that health care facilities provide the vaccine free of cost.¹²⁵ Those who refuse hepatitis B vaccination must sign a statement declining the vaccine. Because immunity can wane over time and some people do not respond completely to the series, serologic testing for anti-hepatitis B surface antigen after vaccination and revaccination if immunity is not present may be part of an occupational health strategy at many hospitals.¹¹⁹

In the case of an accidental exposure, the source patient, if known, should be tested for HBV, in accordance with laws regarding informed consent. In those health care workers who have had a three-dose vaccine series and who have documented immunity by serologic testing, there is no need to test the source patient for HBV and no postexposure management is necessary.¹¹⁹ If the health care worker does not have evidence of serologic immunity, the worker should be tested for immunity. In those without immunity and those who have not been vaccinated, hepatitis B immune globulin (HBIG) can be administered as PEP, together with the hepatitis B vaccine, if indicated.¹¹⁹ HBIG will provide temporary protection from HBV for 3 to 6 months.¹¹⁹

HCV, like HBV, is a bloodborne virus that causes acute viral hepatitis. However, unlike HBV, HCV is not transmitted efficiently through percutaneous exposure to infected blood. The incidence of seroconversion after accidental percutaneous exposure to HCV varies but is estimated to be between 0.5% and 2%.¹²⁶ Of those who are exposed to HCV and develop acute infection, the infection is cleared in only 15% to 25% of cases.¹²⁶ The majority of infections progress to a chronic stage, and 5% to 20% of infections cause cirrhosis over the long term.¹²⁶

In the United States, there were 2967 cases of acute HCV reported in 2016. Three to 4 million people in the United States have chronic HCV.¹²³ Unfortunately, there is no vaccine or PEP available for HCV, but there are effective treatments, including direct-acting antiviral agents, which can lead to complete clearance of infection in more than 90% of patients who are treated.¹²⁷

Because HCV is treatable, health care workers who have an accidental exposure to HCV should be tested for anti-HCV within 48 hours of an exposure. All those tested without evidence of prior exposure should have repeat HCV RNA testing 3 weeks or greater from the time of initial exposure. If there is evidence of HCV infection, the health care worker should be referred for expert monitoring and treatment, if the primary infection is not cleared.

Accessing multidose vials for multiple patients, particularly propofol vials, has been linked to the transmission of HBV and HCV in many health care-associated outbreaks. In a 2006 high-profile case, five cases of HBV and six cases of HCV were linked to a single anesthesiologist at an

endoscopy center, who was found to have used a syringe that had been in contact with a chronically infected patient to access a multiuse propofol vial, contaminating it.¹²⁸ Subsequent use of the propofol vial in other patients resulted in the transmission of HBV and HCV. Safe injection practices are part of standard infection precautions. The CDC recommends that vials should never be entered with a used syringe, even with a new needle or cannula. Medication vials in the immediate patient treatment area should always be single use.^{80,85}

HIV is an RNA retrovirus that is spread through blood or serum-derived fluid. Once introduced into a host, HIV binds to cells with a CD4+ surface antigen (such as helper T lymphocytes) and replicates by integrating its viral DNA into the host cell DNA to establish a persistent infection.¹²⁹ According to statistics from the Joint United Nations Program on HIV/AIDS, in 2016 there were approximately 36.7 million people with HIV, with the most affected region being sub-Saharan Africa. HIV is mostly transmitted from person to person through unprotected anal or vaginal intercourse. HIV can also be transmitted from mother to child or through sharing or accidental exposure to an HIV contaminated needle.

If a health care worker has a percutaneous exposure to HIV, the risk of infectious transmission is low, approximately 0.3%. The risk of transmission after mucous membrane exposure (such as being splashed in the eyes or mouth with infected blood) is even lower (approximately 0.09%).¹³⁰ Injuries from patients with higher viral loads, use of hollow-bore needles, and deeper injuries are more likely to lead to HIV transmission.

The acute phase of HIV infection follows 3 to 6 weeks after exposure, with a nonspecific, febrile viral syndrome similar to influenza infection or mononucleosis that lasts 2 to 6 weeks.¹²⁹ The infection then enters an asymptomatic phase that can last for many years before the appearance of signs of immunodeficiency. Antibody screening tests for HIV will be positive in most patients by 8 weeks after the initial infection.¹²⁹

After a high-risk exposure to an HIV-infected patient, health care workers should immediately contact their onsite occupational health department for postexposure management. The Clinician Consultation Center PEPLINE service offers free clinician advice on the risk of disease transmission and initiation of PEP.¹³⁰ Following an accidental occupational exposure, the source patient should be tested for HIV status with a rapid HIV test, observing local regulations regarding consent for HIV testing. Rapid HIV tests are considered sensitive and specific enough by the CDC to determine the need for PEP without additional testing.¹³¹

PEP with antiretroviral drugs is available and is most effective when given as soon as possible after the exposure, usually within 72 hours.⁵⁰ The decision to use PEP is nuanced and is based on the likelihood of exposure (i.e., if the source is known to have HIV, PEP is more strongly recommended versus if the source has an unknown status or the exposure was from an unknown source such as a sharps box). PEP can always be started and then discontinued after more information is obtained or expert consultation is available. A full course of PEP most commonly consists of a 28-day, three-drug antiretroviral regimen of tenofovir, emtricitabine, and raltegravir or dolutegravir. The most common side effect of

PEP is gastrointestinal upset, with fatigue, headache, and insomnia also contributing to poor PEP adherence. Tenofovir can cause renal toxicity and is relatively contraindicated in those with impaired renal function.

Regardless of whether PEP is initiated, the CDC recommends reevaluating exposed health care workers within 72 hours and, at a minimum, follow-up HIV testing of the exposed health care worker at 6 weeks, 12 weeks, and 6 months after exposure.¹³¹ A systematic review of PEP found that the risk of HIV infection was 89% lower among animals receiving PEP after an exposure to HIV than those who did not receive PEP.¹³² One small retrospective study of the use of zidovudine alone for PEP in health care workers exposed to HIV showed that the use of PEP resulted in a risk reduction of 81% for HIV seroconversion.¹³³

Emerging Diseases

Occasionally, novel or previously nonvirulent infectious agents shift or become more pathogenic, creating anxiety and uncertainty among the public and the health care sector. In the presence of such outbreaks, medical centers must have plans and procedures in place to contain infectious agents, educate workers, and protect them from infection.

Prion diseases, caused by abnormal pathogenic agents able to induce misfolding of normal cellular proteins in the brain, lead to an incurable progressive neurodegenerative disease that usually results in death within 1 year of symptom onset. Creutzfeldt-Jakob disease (CJD), which caused approximately 500 deaths in the United States in 2016, is sporadic or familial in 95% of cases.¹³⁴ However, there have been occurrences of iatrogenic transmission of CJD through human-derived growth hormone, dural and corneal grafts, and the use of contaminated neurosurgical equipment.⁸⁰ Fortunately, since the implementation of routine sterilization practices, there have been no equipment-related cases¹³⁵ and, in the United States, no cases have been linked to percutaneous exposure or bloodborne transmission.⁸⁰ Variant CJD (vCJD) is a separate degenerative disorder caused by the same agent responsible for bovine spongiform encephalopathy (mad cow disease) in cows. vCJD transmission has largely been linked to the ingestion of contaminated meat in the United Kingdom; however, there were two reported cases of bloodborne transmission of vCJD.⁸⁰ SP should be used when caring for patients with suspected or confirmed prion disease. There are special guidelines for the reprocessing of surgical equipment used in patients with prion disease available through the World Health Organization.

Ebola is one of a group of viruses, including Marburg, Lassa, dengue, and yellow fever, that causes viral hemorrhagic fever syndromes.⁸⁰ Between 2014 and 2016, and again in 2018, in West Africa there were outbreaks of Ebola virus disease (EVD), with at least 28,652 cases of Ebola and 11,325 suspected deaths.^{135a} EVD is transmitted readily to health care workers and is acquired through direct contact (through broken skin or mucus membranes such as the eyes, nose, or mouth) with blood or body fluids from an infected person but not via aerosol droplets.⁸⁰ The CDC recommends that all health care workers caring for patients with EVD use an N95 mask or higher respirator in addition to full contact and droplet precautions, to prevent accidental exposure of a mucus membrane to contaminated body

fluid. Health care workers caring for patients with viral hemorrhagic fevers should go through special training on donning and doffing PPE, supervised by a trained observer to ensure that equipment is safely removed without contaminating the surrounding area.

Substance Use Disorders

Medical personnel treat patients suffering from substance use disorders (SUDs) every day. The psychiatric and social impacts are evident. Associated medical conditions such as HCV, HIV, bacteremia, and endocarditis require the highest level of care. Health care workers are not spared from this family of diseases. The Accreditation Council for Graduate Medical Education (ACGME) Common Program Requirements state that residents in anesthesiology understand their role in the recognition of impairment; however, recent work by Warner and associates has demonstrated that the problem may in fact be increasing and that the lives of promising young physicians are lost every year due to the use of drugs.^{136,137} Some of the factors thought to lead to SUDs in health care personnel include access to potent substances, exposure to a high stress environment, long hours, variable shifts, and a culture of self-medication. Detection of SUDs is difficult because work may be the last area to suffer. Self-policing has been the main mode of detection, but organizations are currently incorporating more objective measures such as surveillance of medical records and drug testing. Timely and compassionate intervention is critical when an individual is suspected of performing under conditions of impairment, especially with SUDs, which threatens the safety of the resident, as well as that of the patient. Comprehensive treatment is critical for those diagnosed with an SUD.

EPIDEMIOLOGY

The incidence of SUDs including alcohol abuse among anesthesia personnel is the same as that in the general population, 10% to 20%. The incidence of misuse, abuse, or dependence on drugs other than alcohol among anesthesiologists has remained consistent over the years, at 1% to 2%.¹³⁸⁻¹⁴¹ A survey of Canadian residency program directors revealed a similar rate among residents, at 1.6%.¹⁴² Bell and associates surveyed 2500 practicing nurse anesthetists and reported an incidence of 9.8%.¹⁴³ A lower rate was reported for fellows (0.4%). The problem of SUDs among anesthesia personnel is not limited to the United States, because studies in Australia, New Zealand, and Brazil¹⁴⁴ document similar results.¹⁴⁵⁻¹⁴⁷

The most common substance misused by anesthesia personnel has traditionally been opioids, as indicated in multiple studies (Table 88.6).^{137-140,145-147} Over the past several years there has been an increase in the abuse of other drugs, including propofol, ketamine, and remifentanil, as well as volatile anesthetics.¹⁴⁸

Since its introduction in 1986, the incidence of propofol abuse appears to be increasing. In a 2007 survey of 126 academic anesthesiology training programs, Wischmeyer and associates¹⁴⁹ reviewed 25 cases of propofol abuse and determined an incidence of 0.1% per decade, a fivefold increase from a previous study by Booth et al.¹⁴⁰

TABLE 88.6 Most Common Drugs of Abuse

Study (Year)	Cohort (Years)	Most Used Substances
Ward (1980)	289 anesthesiology programs in United States 1970-1980	Meperidine Fentanyl Morphine Diazepam Other Alcohol
Menk (1990)	159 anesthesiology programs in United States 1975-1989	Parenteral opioids Diazepam Alcohol Inhalational agents
Weeks (1993)	Anesthesiology training programs in Australia and New Zealand 1981-1991	Opioids Cannabis Cocaine Alcohol Benzodiazepines Barbiturates
Bell (1999)	2500 Actively practicing certified registered nurse anesthetists in United States 1999	Benzodiazepines Propofol Inhalational agents Opioids Dissociative drugs (ketamine)
Booth (2002)	Academic anesthesiology programs July 1990-July 1996 (residents) July 1990-June 1997 (staff)	Fentanyl Sufentanil Cocaine Nitrous oxide Meperidine Midazolam Diazepam Ketamine Halothane Propofol Others
Fry (2005)	Anesthetists in Australia and New Zealand (128 anesthesiology departments) 1994-2003	Opioids Induction agents Benzodiazepines Alcohol Inhalational agents
Palhares-Alves (2012)	Anesthesiologists treated in a reference program in Brazil 2002-2009	Opioids Benzodiazepines Alcohol Marijuana Amphetamines Cocaine/Crack
Warner (2013)	Anesthesiology training records from ABA, DANS, NDI 1975-2010	Opioids Alcohol Marijuana/Cocaine Benzodiazepines Propofol
Fry (2015)	Australian and New Zealand anesthesia trainees 1981-2013	Opioids Propofol Benzodiazepines Alcohol Recreational drugs
Zuleta-Alarcon (2017)	Literature search on PubMed prior to April 11, 2016. Ovid MEDLINE search 1946-April 11, 2016, Anesthesia care providers. PubMed keywords: anesthesiology, anesthesia personnel, AND substance-related disorders. Ovid keywords: anesthesiology, OR anesthesia, OR nurse anesthetist, OR anesthesia care provider, OR perioperative nursing, AND substance-related disorders	Nonopioid anesthetic drugs Propofol Benzodiazepines Inhalational anesthetics Ketamine

ABA, American Board Association; DANS, Disciplinary Action Notification Service; NDI, National Death Index; OR, operating room. (Table, Study Characteristics) Modified from Zuleta-Alarcon, A, Coffman JC, Soghomonyan S, et al. Non-opioid anesthetic drug abuse among anesthesia care providers: a narrative review. *Can J Anesth/J Can Anesth.* 2017;64:169-184.

The incidence of death was 28%. Health care providers that abuse propofol tend to be female, have training as an anesthesiologist or nurse anesthetist, and work in the operating room theater.¹⁵⁰ Propofol abuse tends to present early in dramatic fashion such as a motor vehicle accident or other physical injury in the setting of acute intoxication.

Ketamine may make up approximately 2% to 4% of abused substances.^{137,139} Ketamine causes hallucinations as well as calming effects.^{148,151} The risk of death associated with ketamine may be less than opioids among impaired providers, but the acute impact of delusions, delirium, and confusion have the potential to result in injury. Long-term effects include memory impairment, attention dysfunction, tolerance, and flashbacks.

Inhalational anesthetic drug abuse comprises approximately 2% to 5% of misused substances among anesthesia providers.^{137,139,146,148} A 2008 survey demonstrated that 22% of anesthesia training programs had at least one provider who had been impaired by inhalational anesthetics and that 26% of those died.¹⁵² N₂O was the most commonly abused drug, followed by volatile anesthetics. Only 22% of those individuals who abused such anesthetics were ultimately able to return to work. The report noted that only 7% of the anesthesia departments had any pharmacy accounting for inhalational anesthetics.

Anesthesia providers may misuse benzodiazepines to relieve stress and to treat insomnia.¹⁴⁸ Benzodiazepines are the drug of choice for 5% to 15% of anesthesiologists impaired by SUD and are the drug of choice of impaired SRNAs.^{137,139,143,145,146} Remifentanil was introduced in 1997 as an opioid with a rapid onset and rapid rate of degradation. Remifentanil does have typical opiate-like effects, but when compared with fentanyl, its significantly shorter duration of activity makes it less likely to be abused than fentanyl. Baylon et al. noted that remifentanil is unlikely to be used "on the street," but if access to the medication and infusion pumps increases and addicts recognize minimal observable effects, abuse of the medication may increase.¹⁵³ Remifentanil abuse has been reportedly used by a resident as a foray into opioid abuse.¹⁵⁴

ETIOLOGY

The underlying etiology of SUDs among anesthesia providers, who are presumably more intimately aware of the risks, remains undetermined. No study has clearly identified individual factors, and those often cited are not specific to the practice of anesthesiology. Risk factors for SUDs may be biologic, psychological, or occupational.¹⁵⁵

Hiroi and Agatsuma surmise that certain individuals are more likely to transition from substance use to dependence if they are genetically susceptible based upon animal studies.¹⁵⁶

A family history of SUDs has also been identified as a risk for relapse among addicted individuals.¹⁵⁷ Individuals receiving medical education within the United States had higher rates than those from other countries.¹⁵⁸

Personality may play a role in the likelihood of developing SUD. Trinkoff and Storr studied the incidence of SUD among nurses and noted that those in emergency medicine

and critical care had higher rates than other nursing specialties.¹⁵⁹ These areas of practice are like those in which anesthesiologists work.

Anesthesiologists directly obtain and administer medications to patients. A review of anesthesiologists treated for SUDs by the Medical Association of Georgia Impaired Physician Program concluded that 85% of residents in the program selected anesthesiology because of access to medications and drugs.¹⁶⁰ Emergency and critical care nurses,¹⁵⁹ and pharmacists also have access to medications and have high rates of SUDs.¹⁶¹

Anesthesiologists, like other physicians, often self-medicate rather than seeking appropriate medical care from their physician. Christie and colleagues reported in 1998 that more than 50% of prescription medications used by trainees were self-prescribed.¹⁶² Unpredictable schedules, ease of access to medications, and knowledge of medical conditions were cited as potential causes of this behavior,¹⁶² as may the lack of access to health care providers.^{162,163} Fortunately, a study showed that the incidence of self-medication may be decreasing.¹⁶⁴

IMPACT

Health care providers who suffer from SUDs generally divert their drugs from the health care facility at which they work. The National Association of Drug Diversion Investigators defines drug diversion as "any criminal act or deviation that removes a prescription drug from its intended path from the manufacturer to the patient. This can include the outright theft of the drugs, or it can take the form of a variety of deceptions such as doctor shopping, forged prescriptions, counterfeit drugs, and internal smuggling."¹⁶⁵

SUDs in health care providers affect their well-being, their career, and their family. Individuals with SUDs have high rates of divorce and marital discord. The cost of rehabilitation and follow-up care is significant. Problems with medical licensing are common. In addition, the individual with an SUD in a sensitive position may carry the stigmata of impairment. The death rate for anesthesiologists with SUDs is 9% to 15%.^{138,139,158}

It is generally believed that the impact of SUD is largely limited to the individual with the disease, but an increasing number of reports of injury to patients is being published. Shaefer and Perz reported on public outbreaks of communicable diseases such as HCV, HBV, and other organisms in hospital settings where health care providers abusing drugs placed patients at risk.¹⁶⁶ These situations arose because of providers diverting drugs from the work environment for their own use.

PREVENTION AND DETECTION

Prevention of SUDs among health care providers has been largely limited to education on the impact of drug use. These efforts may include presentation of videos demonstrating the death of a promising young resident physician and the impact on his family. Individuals with a history of SUDs are often invited to share their stories of drug use, detection, and recovery. Members of the state Physicians Health Services are often invited to present resources to

TABLE 88.7 Behaviors and Indicators that Could Indicate Substance Use Disorder

Potential Indicators at Work	Potential Indicators at Home	Physical
Changes in behavior (wide mood swings, anger, euphoria, gossip by others)	Withdrawal from family and friends	Pinpoint pupils
Progressive increases in narcotic use for anesthetic management	Changes in behavior, mood swings, anger	Diaphoresis, tremors
Recurrent documentation errors related to medications	Frequent, unexplained illness	Odor of alcohol on breath
Preference for working alone	Risk behaviors—gambling, extramarital affairs	Weight loss
Frequent requests for bathroom breaks	Decrease in sexual drive	Wearing of long-sleeved gowns (to hide needle tracks or prevent withdrawal chills)
Unusual willingness to provide breaks for others or work additional shifts/calls	Finding of drugs and syringes at home	
Frequent appearances in hospital when not on call	Increased use of alcohol	
Falling asleep during rounds, in OR	Increase interactions with individuals who use illicit substances	
Unexplained absences		
Difficulty contacting when on call		
Excessive postoperative pain in patients		
Direct observation of use		
Sudden death		

OR, Operating Room

support physicians. Lutsky et al. reported that in 1993, only 15% of anesthesiologists could report receiving any education on impairment during their residency.¹⁶⁷ Booth and colleagues reported that, despite enhanced education over the course of their study, the incidence of SUDs had not decreased.¹⁴⁰

Detection of SUDs has traditionally relied upon colleagues observing and reporting performance characteristics that could indicate SUDs (Table 88.7). However, many health care professionals will not report or even seek assistance for colleagues who may be impaired. In an investigation of reporting behaviors, only 64% of physicians agreed with the statement, "Physicians should report all instances of significantly impaired or incompetent colleagues to their professional society, hospital, clinic and/or relevant authority."¹⁶⁸ Multiple reasons for not being willing to report were cited, including the perception that it is not one's responsibility to report or a fear of retribution for reporting. Because reliance on observation by colleagues and reporting has proven unreliable and death is too often the initial presenting factor for SUD, institutions are starting to use new measures, including anesthesia record surveillance, vigorous control and testing of returned substances, and drug testing of providers.

Medical record surveillance is the practice of comparing the anesthetic record to the medications that have been dispensed for patient use. Pharmacists or other health-care personnel manually review the record and compare documentation with the amount of medication returned. Inconsistencies may indicate medication diversion from the patient. Discrepancies in practice patterns may also

be detected by record surveillance. Epstein and colleagues retrospectively reviewed medical records through a commercial drug-dispensing system to evaluate discrepancies that could indicate diversion.¹⁶⁹ Factors such as high use of opiates, excessive medication wastage, and late transactions on canceled cases were not indicative of diversion, whereas transactions late in the day after completion of cases and transactions that occurred at locations different from where the procedure occurred were associated with episodes of diversion. These authors posited that a surveillance scheme used in real time might identify episodes of diversion earlier than traditional behavioral observation and reporting methods, an assertion they later validated prospectively.¹⁷⁰

Most organizations use the practice of witnessed wasting of controlled substances. Such practice involves a second individual observing and documenting that controlled substances remaining after a case are wasted. This system relies upon the integrity of several steps: that the elimination of the entire substance occurs, that both providers are honest, and that the wasted substance is a controlled substance at the appropriate concentration. Leaders at the Mayo Clinic recognized these potential weaknesses and developed a vigorous system to prevent diversion. The system requires that all unused substances are returned to a secure, locked box. The box is returned to the pharmacy, where the amount returned is reconciled with the dispensing record and anesthesia record. Random samples are periodically sent for toxicologic analysis. This process occurs under video surveillance to prevent diversion by the pharmacy department.¹⁴¹ This system has successfully identified

multiple health care providers and other personnel diverting substances.

Two major events resulted in widespread use of urine drug screening to reduce the incidence of SUDs. During an investigation after an aircraft accident aboard the USS Nimitz in the early 1980s, it was discovered that nearly 50% of the ground crew tested positive for illicit substances.¹⁷¹ In addition, the passage of the Drug-Free Workplace Act of 1988 required that all federal contractors and all federal grantees establish drug-free workplaces to receive a grant of contract from the U.S. government.¹⁷² The act included the provision that individuals in safety-sensitive professions could be subject to drug testing. The Department of Anesthesia, Critical Care, and Pain Medicine of the Massachusetts General Hospital (MGH) first reported the feasibility of drug testing in anesthesiologists 2008.¹⁷³ The incidence of SUDs prior to implementation of testing was 1% among all residents and 2.2% among first-year residents. There were no cases of SUDs reported within the first 4 years of implementation of the program, although the results were not statistically significant. In 2010 Tetzlaff and associates reported their experience developing an SUD prevention program at the Cleveland Clinic's Anesthesiology Institute.¹⁷⁴ The clinic implemented a comprehensive substance abuse prevention protocol that included randomized urine toxicology screening and "for cause" testing that would be initiated in the event of a significant decline in performance. Assessment of the prevention program is ongoing.

Implementation of a drug-testing program is not without challenges and concerns. Senior physicians may opine that their years without a problem indicate that they are without risk and should not be subject to an invasive test without cause. Although Alexander and colleagues reported that the highest rate of SUDs among anesthesiologists occurred within the first 5 years after medical school, the risk is never eliminated and extends into the senior years of one's career.¹⁷⁵ Some argue that if drug testing is not a condition on a contract than it cannot be required. Initially, participation in the MGH drug-testing program was voluntary, but testing became mandatory for all physician members in 2005.

False-positive results are a legitimate concern for those tested, as well as for those administering the program. For example, one of two false-positive tests at MGH was likely due to the consumption of the poppy seeds in a bagel eaten the morning of testing. It was found that the testing threshold for morphine (300 ng/dL) was set far lower than the federal level of 2000 ng/dL.¹⁷⁶ In the second event, the initial enzyme-linked immunosorbent assay reported the presence of ketamine, whereas confirmatory gas chromatography/mass spectroscopy reported a result that was indeterminate. Policy dictates that a second sample is collected at the original test. This second sample was sent to another certified laboratory where a "negative" result was found.¹⁷⁶ Some test results may be positive due to legitimate medication use for which an individual has a valid prescription. A certified, unbiased Medical Review Officer trained to the standards of the Department of Health and Human Services Substance Abuse and Mental Health Services Administration Center for Substance Abuse Prevention should review all results.¹⁷⁷

INTERVENTION, TREATMENT, PROGNOSIS, AND REENTRY

SUDs curtail promising careers and claim the lives of anesthesiologists every year.¹⁷⁵ Studies have shown that death is the initial presentation in 9% to 16% of cases.^{138,139,178} Residents who have an SUD during their training have a markedly increased risk of death after training compared with their colleagues without an SUD.¹⁴¹

When an SUD is identified or suspected, it is critical that concerned and compassionate colleagues intervene to prevent injury or harm to patients and to help the impaired individual. An organized, structured, and supportive plan to present the concerns to the impaired individual is critical. Such an "intervention" is more likely to maintain the confidence of the individual than a "confrontation" where the individual feels that guilt is presumed.¹⁷⁹ A suggested approach used at MGH is that a consistent team including the director of the SUD prevention program, another department leader, and a designated psychiatrist familiar with SUDs and the department's policy should be involved in all interventions. Other individuals such as a mentor or certified registered nurse anesthetist (CRNA) leader may be included when appropriate. The intervention team discusses each case before meeting with the individual. The individual is removed from clinical duty in a confidential manner. The issues of concern are presented in a supportive and nonconfrontational manner. If additional drug testing is indicated, the individual is escorted for testing. In the case of admitted or demonstrated SUD, treatment is required. Should an individual refuse to seek care, an immediate report to the Board of Registration in Medicine is made. When it is uncertain whether an SUD is the cause of impaired performance, a medical leave of absence is granted pending completion of evaluation and testing. In either circumstance, access to controlled substances and the operating room is restricted, pending outcome of an investigation.

It is critical that factors other than SUDs be considered, because the "impaired" anesthesiologist is not necessarily an "addicted" anesthesiologist.¹⁸⁰ Other issues that may lead to inadequate or unsafe performance may be depression, anxiety, financial difficulties, and family struggles, and other medical illness may manifest in similar ways to SUDs. Treatment and recovery after a diagnosis of an SUD is complicated for professionals whose livelihood involves daily exposure to the substances which they misuse. In a report by the California Physicians Diversion Program,¹⁸¹ anesthesiologists made up 5% of the physicians in California yet 17.4% of those in the program. The recovery rate was 69%, with the majority reentering anesthesiology (96%). The relapse rate among those using opioids was 16%. Paris and Canavan studied anesthesiologists compared with physicians from other specialties.¹⁸² The relapse rate was high (40.6%) but like other specialties, relapse was less likely when the individual entered another specialty. In a 5-year longitudinal study of physicians enrolled in physician health programs (PHPs) between 1995 and 2001, a subset of 102 anesthesiologists of the 904 physicians was independently analyzed.¹⁸³ Anesthesiologists primarily enrolled in the recovery programs due to opioid abuse, whereas alcohol was the most common drug of abuse for other physicians. Compared with other physicians, anesthesiologists had

no higher rate of mortality, relapse, or disciplinary action during the period of recovery. The study's conclusions are limited because only 16 of the 48 PHPs elected to participate because of lack of resources or regulatory impediments to participation. Factors associated with increased risk of relapse specifically among physicians have not been studied well. Domino and colleagues reviewed risk factors for physicians in the Washington Physicians Health Program in 2005.¹⁵⁷ Among a cohort of 292 health professionals enrolled in the program, 74 had at least one relapse (25%). Those with a family history of SUD, as well as individuals whose drug of misuse was a major opioid and who had a coexisting psychiatric disorder, had higher risks of relapse. Individuals with all three risk factors—family history, a coexisting psychiatric illness, and abuse of a major opioid—had the highest relapse risk.

States, hospitals, and departments often rely on the help of PHPs to guide the recovery of physicians impaired by any condition, particularly SUDs. PHPs are not addiction programs, but they do provide active case management and guidance through the diagnosis, treatment, recovery, and reentry process. Individuals with SUDs are required to sign contracts with a PHP and agree to treatment (usually inpatient), follow-up, monitoring, and other stipulations during recovery. PHPs offer a temporary safe haven during the initial phases of management. PHPs work closely with state medical boards to ensure that a physician is compliant with requirements of a comprehensive recovery process.¹⁸⁴

Specialists in the treatment of physicians with SUDs have identified six lessons that appear to promote long-term recovery through PHPs¹⁸⁵: (1) Successful programs promote a zero-tolerance policy for any use of alcohol or other nonmedical drugs. (2) Evaluation of individuals should be complete, comprehensive, and patient-focused rather than merely repeating the same practices for every single patient. (3) Frequent random drug testing for both alcohol and drugs serves as a constant reminder of the obligation of the individual being treated. (4) PHPs use leverage with medical boards, hospitals, and medical groups, which may serve as a deterrent to relapse. (5) PHPs define what constitutes a relapse and act in a quick and certain way with meaningful consequences. (6) Lastly, those in recovery working through PHPs generally must be involved in 12-step programs such as Alcoholics Anonymous or Narcotics Anonymous.

The use of naltrexone may reduce the chance of relapse among anesthesiologists in recovery. The state of Florida mandates that anesthesiologists referred for opiate disorders are contractually required to use naltrexone for 2 years.¹⁸⁶ Naltrexone has side effects such as headache, fatigue, insomnia, anxiety, and nervousness, all conditions that can impair performance. In a small prospective study, 11 anesthesiologists treated with naltrexone were compared with 11 controls: only one individual in the naltrexone program relapsed while 8 of 11 (72%) in the untreated group relapsed. Those on naltrexone also had higher rates of return to the practice of anesthesiology.

Whether SUD residents in anesthesia are returned to their training programs or are retrained in either a different specialty or another career is even more controversial. In a review of outcomes for residents treated for chemical dependency, most program directors (80%) had at least one

impaired trainee and 19% reported a pretreatment fatality.¹⁸⁷ A high percentage (92%) of trainees attempted reentry into anesthesiology, but only 46% ultimately completed training. The rate of death was 9%. A survey of anesthesiology residency training programs in 2007 showed that nearly two thirds of program directors had at least one resident who required treatment for SUDs.¹⁸⁸ The relapse rate after treatment was 29%, and death occurred in 10%. Despite these statistics, 43% believed that residents should be allowed to continue their training. Bryson and Levine conducted an intensive 12-month posttreatment program involving an anesthesia simulator followed by gradual reintroduction to the clinical practice of anesthesia.¹⁸⁹ Five residents participated in the program, and three (60%) successfully finished their training program. Two of those individuals remained in recovery at 3 and 6 years, whereas one relapsed at 9 years.

The decision whether to return or retrain is difficult, and circumstances vary on an individual basis. Residents often do not have the social and financial supports of graduated physicians, and they are exposed to the substances of risk for perhaps 40 more years. In addition, their youth may predispose them to denial of the disease.

SUDs among anesthesiologists remain a problem. Enhanced education and substance control measures should continue. Other efforts such as drug testing should be explored. When an individual is suspected or found to have an SUD, a timely, compassionate, and professional intervention is necessary to ensure the safety of the individual and patients.

Fatigue

Excessive tiredness due to inadequate sleep, physical illness, or other causes can result in fatigue. In general, physicians are not able to compensate for loss of sleep or to recover from illnesses because of the requirements of their work environment to patient care issues or work structures. Fatigue may place patients at risk of injury, as well as impact the health and safety of anesthesiologists. Fatigue in trainees became a public concern with a case involving Libby Zion, a young woman whose unfortunate death was determined in court to be related to 36-hour duty periods worked by the physicians providing her care. Physicians should understand the causes of fatigue, the impact on patients and themselves, and the means to manage the challenges ever present in a difficult and unpredictable work environment.

INCIDENCE AND IMPACT

Few studies of the impact of fatigue have been performed in the population of providers involved in anesthesia care. Gravenstein and colleagues conducted a survey of anesthesiologists, residents, and CRNAs wherein residents and CRNAs noted that they occasionally worked beyond what they would consider their limitations and that they had made errors associated with fatigue.¹⁹⁰ Ten years later, Cao and colleagues evaluated the differences in performance during day and night shifts among residents. Residents had a more negative mood at night, although workload ratings and alarm response times were no different between the two

TABLE 88.8 Accreditation Council for Graduate Medical Education Duty Hour Rules and Modifications

2003 ACGME Duty Hour Standards	2017 ACGME Clinical Experience and Education Modifications
80-h weekly limit (averaged over 4 weeks)	Clinical work done from home must be counted toward the 80-h weekly maximum
10 h between work shifts (suggested)	All residents must have at least 14 h free of clinical work after 24 h of clinical assignments
Limit of 24 h of continuous duty plus 6 for transition of care	Clinical work for all residents must not exceed 24 h of continuous schedule clinical assignments
One day in 7 free from all obligations	
In-house call no more than every 3 nights	
Options for some programs to request 8 h additional time	Clinical work exceptions may be granted by the RRC up to a maximum of 88 h based on sound educational rationale
	Residents who have handed off work have the flexibility to remain at work in unusual circumstances for the benefit of patient care. Hours must count towards the 80-h work week

ACGME, Accreditation Council for Graduate Medical Education; RRC, Residency Review Committee.

shifts.¹⁹¹ More recently, Husby and colleagues studied the impact of short- and intermediate-duration hospital calls on anesthesiologists.¹⁹² Reaction times were significantly worse after 18-hour shifts, but not after shorter shifts. The incidence of adverse events has been found to be higher later in the day; the lowest rate of adverse events was found at 9:00 AM, whereas the highest rate was at 4:00 PM.¹⁹³

The impact of fatigue on the safety of the physicians themselves may be significant. Extended work duration of interns is associated with increases in percutaneous injuries.¹⁹⁴ A lapse in concentration and fatigue were the most commonly cited contributing factors. Injury was more common during the night shift than during the day. Depression, fatigue, and sleepiness were associated with a higher likelihood of a motor vehicle incident in resident physicians.¹⁹⁵ The personal lives and well-being of trainees may also be impacted by sleep loss and fatigue. A study of 149 resident-physicians at five academic medical centers revealed that many residents perceived that sleep loss and fatigue had a major impact on their personal lives such that personal and social activities were deferred or postponed.¹⁹⁶

Attempts to restrict duty hours have been implemented by the ACGME. The benefit of limitation of duty hours is unclear, and negative consequences on patient care and education may result. Early studies of the impact of duty hour restrictions demonstrated that when efforts were made to reduce sleep deprivation, medical errors were lower, as were patient hospital length of stay and laboratory tests ordered,¹⁹⁷ but this has not been a consistent finding, and the relationship between duty hour restrictions and quality of care remains controversial.¹⁹⁸

GUIDELINES

Training for resident physicians requires a balance between the safety of both patients and residents, as well as assurance that optimal educational outcomes are achieved. The ACGME implemented duty hour restrictions for trainees in 2003 and updated these restrictions in 2011. At their core, the restrictions included an 80-hour weekly duty limit, 10 hours of rest between shifts, and no more than 24 hours of continuous duty with a limit of 6 hours for transition of care and education.¹⁹⁹ Many potential benefits were anticipated including improvements in patient care, improved resident quality of life and health, and decreased risk of personal

harm due to fatigue.²⁰⁰ At the time of implementation of duty hour restrictions, many physicians anticipated several unintended consequences, including discontinuity of care, an increased work burden on attending physicians, negative impact on professionalism and the perceptions of the profession, poor preparation for the realities of independent practice, a reduction in educational opportunities, and a major economic impact (Table 88.8).

Multiple studies have been performed on the impact of these changes. Ahmed and associates performed a systematic review of the effects of duty hour restrictions in surgery.²⁰¹ There was no significant improvement in patient safety. Their review found that wellness improved, and fatigue and burnout declined after implementation of the 2003 guidelines but further improvements were not seen after the 2011 modifications. The effects on education and training were either a worsening or no change. Written examination scores were unchanged, but passage of oral examinations decreased in surgery.

REQUIREMENTS AND RECOMMENDATIONS

The ACGME Program Requirements for Graduate Medical Education in Anesthesiology require inclusion of formal efforts to educate faculty and residents in the recognition of fatigue, alertness management, and fatigue mitigation. Programs are also required to ensure adequate sleep facilities and safe transportation options after duty.²⁰² The Association of Professional Sleep Societies' Committee on Catastrophes, Sleep, and Public Policy developed a consensus report concluding that human performance is at its most vulnerable period between 1:00 AM and 8:00 AM, with a less pronounced period from 2:00 PM to 6:00 PM (Table 88.9).²⁰³ It is also known that sleep duration less than 7 hours affects cognitive performance involving vigilance, attention, cognitive processing speed, and working memory, and at least 7 to 8 hours are recommended per night.²⁰⁴ Less sleep and patterns associated with chronic sleep deprivation are associated with even more impairment. Recommendations are in Table 88.9.

Researchers at the Mayo Clinic studied whether capping residents' patient census would improve the perception of workload among residents.²⁰⁵ These changes led to improvements in ratings of workload appropriateness and conference attendance. Duty hour violations were

TABLE 88.9 Recommendations of the Association of Professional Sleep Societies

Observation	Recommendation
The time of 1 AM-8 AM constitutes a time span when human medical and performance catastrophes are far more likely to occur A second but less pronounced period from 2 PM to 6 PM constitutes a second period of vulnerability	Increased awareness is necessary. Policymakers are urged to consider relevant aspects of sleep physiology that affect performance.
Inadequate sleep, even as little as 1-2 h, can greatly exaggerate the tendency for error during the time zones of vulnerability	Programs should be developed to identify the signs of sleep-related error in vehicle operation and on the job, particularly in industries that have a responsibility to minimize accidents and effort for the sake of public health and safety
	Industries and services impacting public safety should address the physiologic needs of workers
	Attention should be given to identification of the least adaptive shiftwork schedules and to the implementation of schedules that promote health and safety

Modified from Mitler MM, Carskadon MA, Czeisler CA, et al. Catastrophes, sleep, and public policy: consensus report. *Sleep*. 1988;11:100-109.

decreased, as were patient readmissions, but other safety outcomes, such as the rate of rapid response team and “code blue” events, were unchanged.

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 Complete references available online at expertconsult.com.

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