Objectives  After completing this article, readers should be able to:

1. List preventive efforts that may decrease drowning rates in the pediatric population.
2. Name the physiologic consequences of hypoxic-ischemic injury in drowning victims.
3. Explain the importance of bystander cardiopulmonary resuscitation for pediatric drowning victims.
4. Discuss the appropriate interventions for each stage of drowning-associated cardiac arrest.
5. Specify which pediatric drowning victims may be discharged from the emergency department.

Definitions
Terminology used to describe drowning often has been confusing and inconsistent. To alleviate this confusion, an international consensus conference was convened at the 2002 World Congress on Drowning with the goal of developing uniform terminology. The recently published recommendations define drowning as “a process resulting in primary respiratory impairment from submersion/immersion in a liquid medium.” (Idris et al. 2003) Accordingly, the term “drowning” should be used regardless of the outcome. In addition, the consensus document specifically recommends that confusing and inconsistent terms, such as “near-drowning,” “secondary drowning,” “passive drowning,” “silent drowning,” “wet drowning,” and “dry drowning” be abandoned.

Epidemiology
Drowning is a major source of pediatric mortality and morbidity worldwide. Although differences in lifestyle and exposure to water may affect the circumstances under which drowning occurs in different countries, drowning consistently remains a leading cause of death throughout the world. In the United States in 1998, more than 1,500 children younger than 20 years of age died from drowning, making it the second leading cause of accidental childhood death. For children 12 to 23 months of age, drowning was the leading cause of accidental death and the second leading cause of death overall. There is less information concerning morbidity, but it is estimated that for each drowning death, there are one to four nonfatal drowning events requiring hospitalization. Such hospitalizations often result in prolonged disability requiring considerable monetary and emotional resources.

Within the pediatric population, rates of drowning peak during both the toddler and adolescent years. Age also influences the circumstances of drowning. Among younger children, drowning usually occurs within the home, often during brief lapses in adult supervision. Infants drowned in bathtubs most frequently, either when they are left unattended or as the result of abusive injury. Toddlers typically drown in swimming pools. For both infants and toddlers, physical and cognitive immaturity limits their ability to rescue themselves from water. Adolescent drowning frequently occurs in natural bodies of water and is associated with risk-taking behavior and intoxication.

Although most drownings occur in previously healthy children, certain pre-existing medical conditions may play a role. Children who have seizure disorders have a risk of drowning four times that of the general population. Cardiac arrhythmias have been
implicated in a small number of drowning deaths. Swimming, particularly diving in cold water, may serve as a trigger for some patients who have long QT syndrome.

Prevention
Drowning rates have been declining over the past 20 years, primarily due to improved preventive efforts. However, much remains to be accomplished, and prevention remains the key to further reductions in both mortality and morbidity. It is estimated that in spite of recent efforts, 80% of drownings remain preventable.

Optimal preventive efforts vary by age group. Adult supervision of infants and young children around water is a major focus of preventive efforts, but supervision is not foolproof. A child can enter the water during a brief lapse in the supervisor’s attention. Adults may assume that they will hear sounds of splashing or struggling as a drowning occurs, but most childhood drownings are silent. Therefore, multiple layers of prevention, with barriers between the child and water, are recommended. Proper pool fencing that includes a self-closing, latching gate should surround the pool completely. Such fencing can reduce the incidence of drowning by 50% to 80%.

Prevention for adolescents should focus on water safety education, including the dangers of intoxication while in and around the water.

Although swimming lessons are presumed to improve water safety, no data demonstrate that they actually decrease the risk of drowning. Importantly, swimming skills cannot make a child “drown-proof” under all conditions. In addition, swimming programs are not developmentally appropriate for children younger than 4 years of age, according to the American Academy of Pediatrics.

Pathogenesis
The physiologic consequences of drowning are due primarily to hypoxic-ischemic and reperfusion injuries. The devastating long-term neurologic consequences of drowning occur almost exclusively among patients who have drowning-associated asphyxial cardiac arrests. Patients who do not experience cardiac arrest rarely have significant sequelae.

Drowning-associated asphyxia is caused by laryngospasm, apnea, or pulmonary aspiration of water. Furthermore, when the victim loses consciousness, he or she may vomit and aspirate swallowed water. The resultant hypoxia, hypercarbia, and acidosis can decrease myocardial contractility, elevate pulmonary artery and systemic vascular resistance, and produce cardiac arrhythmias (bradycardia, asystole, ventricular fibrillation). With sufficient duration of submersion, the asphyxial insult inevitably results in cardiac arrest.

Lung injury in drowning patients is characterized by abnormal surfactant function and increased capillary endothelial permeability. This injury leads to increased intrapulmonary shunting, ventilation/perfusion mismatch, atelectasis, and poor lung compliance, which cause further hypoxemia and hypercarbia. When severe enough, this process may lead to acute respiratory distress syndrome (ARDS). Contrary to earlier beliefs, pulmonary injuries from fresh water and saltwater drowning typically do not differ substantially. Moreover, clinically significant electrolyte abnormalities are relatively uncommon after either fresh water or saltwater drowning. Nevertheless, hyponatremia can occur with fresh water drownings and hypernatremia with saltwater drownings.

The most devastating consequence of drowning and the most frequent cause of death is hypoxic-ischemic injury to the brain. The degree of central nervous system injury is related to the duration of untreated cardiac arrest, the effectiveness of initial cardiopulmonary resuscitation (CPR), and secondary cerebral injuries after resuscitation (eg, further hypoxic episodes, inadequate cerebral blood flow, cerebral edema, and hyperthermia).

Clinical Diagnosis and Management
The critical moment in the care of the severely affected drowning victim generally occurs before he or she comes to the attention of medical professionals. The most important determinants of neurologically normal survival are prompt rescue from the water and immediate institution of effective basic life support. Because time is the crucial element, bystander rescue and resuscitation are the most important interventions. Delays in rescue and resuscitation often are lethal. Sadly, although early effective CPR is key to survival, only about 30% of pediatric cardiac arrest victims, including drowning victims, receive bystander CPR.

Resuscitation
It is increasingly clear that there are four stages of cardiac arrest: prearrest, the no-flow stage of untreated arrest, the low-flow stage of CPR, and postresuscitation (Table). Interventions prearrest include drowning prevention efforts and rescue interventions (removal from the water and rescue breathing). Prompt institution of bystander CPR can shorten the untreated arrest stage, and provision of effective CPR can improve the outcome during the low-flow CPR stage. Finally, anticipating and minimizing secondary injuries are important issues postresuscitation.
The hypoxia and ischemia that occur during drowning can result in severe myocardial dysfunction, manifesting clinically as shock. If rescue efforts are not provided, the hypoxic-ischemic shock soon is followed by complete cardiac arrest. With either severe hypoxic-ischemic shock or cardiac arrest, the victim may be clinically unresponsive, exhibit apnea, and have no pulse. Prompt CPR with mouth-to-mouth rescue breathing and effective chest compressions can be lifesaving.

At the earlier phase of hypoxic-ischemic shock, either rescue breathing alone or chest compressions alone can be lifesaving (although the combination is superior). Accordingly, some bystander resuscitation is better than no bystander resuscitation. After full cardiac arrest, the combination of chest compressions plus rescue breathing generally is needed for successful resuscitation. The Heimlich maneuver or other attempts to clear the airway of water not only are ineffective, but frequently are detrimental by inducing emesis and aspiration of gastric contents.

After opening the airway with the head tilt-chin lift maneuver, two mouth-to-mouth rescue breaths should be provided. Single rescuers should provide two rescue breaths before each cycle of 30 chest compressions. New information from animal models suggests that rescue breathing at an excessive rate can impede venous return during CPR and possibly worsen outcome. Consequently, rescue breathing at rates much higher than 20 breaths/min generally should be avoided.

The goal of chest compressions is to maximize cardiac output. Cardiac output is the product of heart rate and stroke volume. During CPR, the primary determinant of stroke volume is the force of chest compressions; the only determinant of heart rate is the rate of compressions. Chest compressions should be provided by pressing the lower half of the sternum to a relative depth of one third to one half of the anterior-posterior diameter of the chest at a rate of approximately 100 compressions/min. Properly performed CPR can achieve cardiac outputs of approximately 10% to 15% of normal, which can be sufficient for successful resuscitation. During every interruption in chest compressions, cardiac output ceases, and there is no blood flow to the heart or brain. Therefore, the mantra for adequate cardiac output during CPR is: PUSH HARD, PUSH FAST, and minimize interruptions.

Although the electrocardiography (ECG) tracing of most pulseless drowning victims shows either bradycardia or asystole, ventricular fibrillation is not uncommon. Because definitive treatment of ventricular fibrillation requires defibrillation, early ECG assessment is indicated.

The child should be transported to a facility where advanced life support can be provided. Pediatric emergency care clinicians should be prepared for the immediate critical care needs of drowning victims. For many practitioners outside of a hospital and in many emergency departments, care of a pediatric drowning victim is an unusual occurrence. Preparation for relatively rare occurrences is difficult. The availability of clinicians who have appropriate pediatric equipment, as well as pediatric emergency experience and expertise, increases the likelihood of successful resuscitation.

Comprehensive evaluation and treatment should begin immediately upon arrival at the hospital. In addition to rapid cardiopulmonary assessment focusing on evidence of shock, the drowning victim should be evaluated for hypothermia and associated trauma as well as for signs of neurologic and pulmonary injury. Drowning events encompass a wide range of severity. The patient may have had a brief immersion with no clinical sequela or a prolonged episode resulting in full cardiopulmonary arrest and all the associated complications.

In nearly all instances, CPR should be continued until spontaneous circulation has returned or until resuscita-
tion is demonstrated to be futile. Although aggressive resuscitation may result in neurologically devastated survivors, no predictive factors can determine early in resuscitation who will or will not do well. All factors used to predict dismal outcomes are imperfect; some children have had unexpected full recoveries despite predictors of “certain” death or devastation. Good outcomes have been reported after submersion for more than 1 hour, when body temperatures were 56.7°F (13.7°C), or when the pH was 6.29. Due to this uncertainty, it generally is recommended that all drowning victims receive aggressive care for the first 24 hours until the prognosis can be better determined.

Shock
Following initial resuscitation, patients often remain in shock, as evidenced by inadequate tissue perfusion. Clinical signs of shock include tachycardia, altered level of consciousness, poor peripheral pulses and perfusion, oliguria, and acidosis. Even when the child is normotensive, he or she may be in a state of compensated shock. Hypotension is the fundamental indicator of uncompensated shock. Following a drowning episode, shock commonly results from postresuscitation myocardial dysfunction, with poor cardiac output due to acidosis and hypoxemia. Fluid shifts with resultant intravascular hypovolemia also may contribute to cardiac instability. Appropriate management requires careful, continuous hemodynamic monitoring. Inotropic support and fluid resuscitation typically are needed to treat postdrowning shock.

Hypothermia
Dramatic recoveries following icy water drownings are well documented, but hypothermia after drowning in non-icy water is strongly associated with prolonged submersion and a consequent poor prognosis. Decisions regarding treatment of drowning-related hypothermia must take into account several factors. Maintenance of mild hypothermia may be indicated in some cases. Existing evidence suggests that induced mild hypothermia after resuscitation can improve outcome for adults after cardiac arrest with ventricular fibrillation. In addition, there are numerous remarkable case reports of children who had excellent outcomes after prolonged submersion in ice water. Although more investigation is needed, maintenance of hypothermia (90° to 95°F [32° to 34°C]) for 12 to 24 hours is a reasonable therapeutic option for children who remain comatose but who are cardiovascually stable following return of spontaneous circulation.

Rewarming should be provided to children who have severe hypothermia (<82°F [28°C]). Rewarming should be considered for moderate hypothermia (82° to 90°F [28° to 32°C]) for children who have cardiovascular instability or shock-related coagulopathy. There are three types of rewarming. Passive warming, whereby the patient is kept warm and protected from wind and cold, can be initiated at the scene but is inadequate in the face of significant hypothermia. Active external warming such as by warmed air or heat packs may cause surface vasodilation, leading to cardiovascular instability. The gold standard for warming patients who have cardiac arrest or ongoing cardiovascular instability is active internal warming, most commonly with cardiopulmonary bypass or extracorporeal life support. Arteriovenous circulation and body cavity lavage (peritoneal, bladder, pleural, gastric) are other methods of active internal warming that have been described in case reports as being effective. Whether therapeutic hypothermia or rewarming is the treatment of choice, hyperthermia should be avoided and treated aggressively.

Trauma
Drowning may occur during traumatic events such as diving, boating, or motor vehicle accidents that result in submersion. In these scenarios, other traumatic injuries must be considered and full trauma evaluation performed. Computed tomography (CT) scans may be useful to diagnose occult cervical spine, intracranial, or intra-abdominal injury. Except in these settings, cervical spine injury in a drowning victim is uncommon. A recent study demonstrated that cervical spine injuries during drowning only occurred when the history or physical examination findings evidenced high-impact trauma.

Hypoxia–Ischemia
The brain is the organ most susceptible to hypoxic-ischemic injury. Unfortunately, the initial neurologic examination on presentation often is of limited use in predicting outcome. Although children who have normal initial examination findings continue to have normal findings, children who present comatose or severely impaired require serial examinations over the following 24 hours to clarify the prognosis. Those who survive and have a good outcome generally demonstrate spontaneous, purposeful movement and normal brainstem function in the first 24 hours.

Measures specifically directed to limiting neurologic injury in the postresuscitation phase have not yet demonstrated benefits for drowning victims. Immediate resuscitation and therapeutic hypothermia are the only measures shown to reduce brain damage in the setting of
hypoxic-ischemic injury. There is no proof of benefit from pharmacologic therapies, intracranial pressure monitoring, or treatments to reduce intracranial pressure.

Optimal supportive care, with attention to adequate oxygen delivery and prompt treatment of seizures, is important to avoid secondary hypoxic-ischemic damage. Hypoglycemia can have detrimental neurologic effects and should be avoided (and treated promptly when it does occur). Hyperglycemia also is associated with worse neurologic outcomes, but it is not clear whether treatment of hyperglycemia improves neurologic outcomes.

**Pulmonary Involvement**

Mechanical ventilation should be directed toward providing normocarbia and adequate oxygenation to injured tissues. Hypercapnia that can increase cerebral blood flow and severe hypocarbia that can result in cerebral ischemia can be deleterious in the postdrowning setting. It is important to provide adequate support while also avoiding either atelectasis or overdistention. Management of mechanical ventilation may be particularly complex in the initial hours after drowning when dynamic changes in lung compliance, airway resistance, and cardiovascular status are common. In this setting, innovative modes of ventilation, including pressure-limited ventilation, airway pressure release ventilation, and high-frequency oscillation, may be beneficial.

Chest radiography may be useful to detect pulmonary involvement, although when abnormalities are seen, they often are nonspecific. Pneumonia should be considered in the presence of infiltrates or consolidation on chest radiography accompanied by leucocytosis, fever, and purulent secretions. Prophylactic antibiotics generally are not indicated. However, for the patient who develops signs of pneumonia, a bacterial cause should be aggressively sought and treated. It is noteworthy that *Aeromonas* can cause a severe pneumonia that develops rapidly after drowning. In the face of clinical pneumonia without culture-proven etiology, antibiotic coverage should be directed toward the nosocomial flora that are prevalent in the institution.

ARDS may occur due to the alveolar-capillary insult imposed by drowning-related lung injury. In addition to drowning, ARDS can result from any process that directly or indirectly injures the lung, including pneumonia, aspiration, lung contusion, smoke inhalation, blood product transfusion, and sepsis. A delay of hours to days between the initial injury and the development of ARDS in other settings is typical, but evidence of ARDS usually occurs more promptly in the setting of drowning-related lung injury.

The diagnostic triad of ARDS is noncardiogenic pulmonary edema, impaired oxygenation, and bilateral pulmonary infiltrates. Clinical manifestations include tachypnea, decreased lung compliance, and worsening hypoxemia leading to respiratory muscle fatigue.

The natural history of ARDS consists of three stages. The initial exudative stage characterized by rapid development of respiratory failure can progress to an inflammatory stage characterized by fibrosing alveolitis and surfactant deficiency. In the setting of drowning-related acute lung injury, surfactant washout or destruction of surfactant during the drowning event may result in surfactant deficiency earlier in the process. The final stage of ARDS is resolution; many patients recover normal lung function, although residual fibrosis may be present in others. Corticosteroids are not indicated acutely for drowning-induced lung disease, but high-dose intravenous glucocorticoids can be beneficial for ARDS that is not resolving. Mortality rates in ARDS patients are high, but the immediate cause of death typically is sepsis or multiple organ system failure rather than respiratory failure.

**Other Organ Involvement**

Renal and hepatic damage and dysfunction also may occur with drowning. The clinical appearance of these injuries often is delayed 24 to 72 hours after the initial hypoxic-ischemic insult. Hepatic injury typically is revealed by elevated transaminase concentrations and, if severe, may include impaired liver function with an elevated bilirubin value, decreased albumin concentration, and prolonged clotting times. The renal injury may manifest as acute tubular necrosis with elevated creatinine and oliguria or anuria.

Attention to a multitude of details involving diverse organ systems is essential to prevent complications in the severely injured drowning victim. When possible, affected children generally should receive their care in a pediatric intensive care unit. In addition, the long-term outcome of the neurologically impaired drowning victim may be improved with a comprehensive rehabilitation program.

Clearly, not all children who suffer a drowning episode require resuscitation or intensive care unit care, and routine admission is not necessary. A large number of children may be asymptomatic or only mildly symptomatic after being retrieved from the water. Children who require no resuscitation and have Glasgow Coma Scale scores greater than 13 on arrival at the emergency department may be candidates for discharge to home after full evaluation and a period of observation. If oxygen saturation and the physical examination findings remain normal by 6 to 8 hours, these children can be discharged.
with close follow-up. Late electrolyte changes or neurologic decompensation rarely are seen in these children. Some otherwise normal children may require admission for safety concerns related to the drowning incident.

The use of chest radiography is debated. Because a chest radiograph is not a reliable predictor of the clinical course, it is not essential in asymptomatic children. Some sources advocate normal chest radiographic findings as a requirement for discharge from the emergency department; others believe that abnormalities on chest radiography should not be used as the sole indicator for hospitalization.

**Prognosis**

The search for predictive factors in drowning victims to guide the aggressiveness of resuscitation has been difficult. The outcome of drowning is closely related to the duration of submersion. When submersion extends beyond 25 minutes, prospects for functional recovery generally have been dismal. However, there are case reports of children surviving neurologically intact after prolonged drowning, particularly in icy water. These case reports tend to indicate the need for aggressive intervention. In addition, accurate determinations of submersion times usually are not available.

Aggressive resuscitation provides the best chance for good survival, but also may lead to increased numbers of neurologically devastated survivors. Several investigators have sought early indicators of poor outcome, including coma, fixed and dilated pupils, low Glasgow Coma Scale score, and scoring systems based on initial presentation. However, no one factor or combination of factors has consistently predicted ultimate outcomes. Unfortunately, studies have been relatively few, and those that have been published included small numbers of surviving patients. These issues deserve further investigation.

For patients who survive initial resuscitation, the ability to predict their outcome improves over time. In one important study, all survivors who eventually had favorable neurologic outcomes showed spontaneous, purposeful movement within 24 hours of admission. These patients recovered normal neurologic status or had minor deficits such as seizures, motor deficits, or learning disabilities amenable to rehabilitation. However, the extent of subtle neuropsychological sequelae in patients who have mild hypoxic-ischemic injuries has not been well studied. Neurologic outcome in patients who remained without purposeful movement at 24 hours after admission for a drowning incident was dismal. These children exhibited severe neurologic deficits, including spasticity, persistent vegetative states, or lack of self-help skills. Serial neurologic examinations may be the most useful source of information to predict the outcome of drowning injury.

Although the brain is the organ affected most by drowning, chronic pulmonary morbidity also may occur. Children may develop new-onset reactive airway disease. Severe chronic lung disease is a rare sequela of childhood drowning.

The outcomes of pediatric drowning-associated cardiac arrests tend to be considerably better than those from other out-of-hospital pediatric cardiac arrests. For example, in King County, Washington, the survival rate in the pediatric population following prehospital cardiac arrest was 32% for drowning victims compared with 7% for all other causes of cardiac arrest.

**Conclusion**

Drowning is a leading cause of pediatric morbidity and mortality throughout the world. Poor outcomes are due largely to drowning-associated cardiac arrest with resultant neurologic injury. The most important intervention to improve outcome from drowning is prevention. Preventative efforts should focus on adequate supervision, pool fencing legislation, and water safety education. Once drowning has occurred, rapid water rescue and provision of effective bystander CPR are critical to limit the duration of hypoxic-ischemic injury. To that end, pediatricians should support the promotion and teaching of CPR. In the postresuscitation stage, continuous cardiorespiratory monitoring and supportive care are the mainstays of care. Further research is needed to identify ways to improve educational interventions regarding water safety, to encourage bystander CPR, and to improve postresuscitation care for critically ill children.

**Suggested Reading**


1. You are invited to speak to a group of high school seniors regarding safety and prevention of childhood accidents. Of the following, the best means of preventing drowning in a home swimming pool is by:
   A. Barring children who cannot swim from the pool area.
   B. “Drown-proofing” toddlers by having them take swimming lessons.
   C. Emphasizing that children never be left unattended near a body of water.
   D. Installing a fence that has a self-closing, latching gate surrounding the entire pool area.
   E. Installing an alarm system that detects water movement in the pool when it is unattended.

2. You are lecturing at a local community adult education class about drowning accidents. Of the following, the best immediate action to be taken by a bystander when a toddler is rescued from a swimming pool and is found to be limp and unconscious with infrequent, gasping respiration is to:
   A. Call the local emergency telephone number for further management.
   B. Immobilize the cervical spine by holding the neck in a neutral position.
   C. Initiate mouth-to-mouth breathing with chest compressions.
   D. Keep the child prone and administer four back blows.
   E. Perform the Heimlich maneuver to expel aspirated water.

3. A 2-year-old boy is brought to the emergency department after a drowning accident in a home swimming pool. The submersion time is estimated to be 2 minutes. He was resuscitated at the pool side by his neighbor and subsequently by the emergency medical technicians during transport to the hospital. On arrival at the hospital, he is receiving manual ventilation through the endotracheal tube. His heart rate is 120 beats/min, blood pressure is 100/60 mm Hg, and rectal temperature 95°F (35°C). Arterial blood gases are: pH, 7.08; Paco₂, 42 torr; and Paco₂, 122 torr. He is comatose, does not respond to verbal stimulation, and exhibits nonpurposeful flexion withdrawal to pain. His pupils are equal and reactive. Neurologic examination 12 hours after the accident shows spontaneous eye opening and purposeful response to verbal and tactile stimulation. Of the following, the best prognostic indicator of his future neurologic outcome is:
   A. Immediate CPR at the pool side and during transport.
   B. Normal oxygenation, ventilation, and acid/base status in the emergency department.
   C. Normally reactive pupils in the emergency department.
   D. Purposeful response at 12 hours.
   E. Young age.

4. A 6-year-old girl is admitted to the intensive care unit after being rescued from a drowning accident in a lake. During the first hour of admission, she receives 60 mL/kg of 0.9% saline for poor perfusion and hypotension. She responds to verbal communication. Over the next 8 hours, she develops a progressive increase in alveolar arterial oxygen gradient. Her arterial Po₂ is 88 torr while breathing 60% oxygen on mechanical ventilation. Chest radiography shows marked worsening of lung infiltrates bilaterally. Her rectal temperature is 100.0°F (37.8°C). Her central venous pressure is 5 mm Hg. Of the following, the most likely underlying mechanism for her deteriorating respiratory status is:
   A. Fluid overload.
   B. Increased pulmonary capillary permeability.
   C. Left ventricular failure.
   D. Progressive viral pneumonitis.
   E. Secondary bacterial infection.