

PEDIATRIC EMERGENCY MEDICINE PRACTICE

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Pediatric Submersion Injuries: Emergency Care And Resuscitation

Abstract

Drowning and submersion injuries are highly prevalent, yet preventable, causes of childhood mortality and morbidity. Although much of the resuscitation of the drowning pediatric victim is basic to all respiratory and cardiac arrest situations, there are some caveats for treatment of this type of injury. Risk factors for drowning victims include epilepsy, underlying cardiac dysrhythmias, hyperventilation, hypoglycemia, hypothermia, and alcohol and illicit drug use. Prehospital care should focus on restoring normal ventilation and circulation as quickly as possible to limit the extent of hypoxic insult. Diagnostic testing for symptomatic patients may include blood glucose level, arterial blood gas level, complete blood count, electrolytes levels, chest radiography, and cardiorespiratory monitoring with pulse oximetry and a rhythm strip. In this review, passive external, active external, and active internal rewarming techniques for treatment of hypothermic patients are discussed. A systematic approach to treatment and disposition or admission of pediatric drowning victims is also included, with extensive clinical pathways for quick reference.

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CME Objectives

Upon completion of this article, you should be able to:

1. Identify specific populations of children at risk for drowning.
2. Describe the pathophysiology of the drowning process.
3. Initiate emergency management of the drowning victim, and manage the hypothermic drowning patient.
4. Recognize the predictors of outcomes and limitations when resuscitating the drowning pediatric patient.

Prior to beginning this activity, see "Physician CME Information" on the back page.

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Case Presentations

A 10-month-old girl is brought to the ED after she had been missing and was finally located at the bottom of the pool after 15 minutes of searching. Rescue breaths were given by bystanders, but on arrival to the ED, she is in full cardiorespiratory arrest with a GCS score of 3. She is intubated, and passive rewarming measures are initiated. After intraosseous access is obtained, 2 doses of epinephrine are given with a return of spontaneous circulation after 10 minutes. The process to admit this patient is initiated...

An 8-year-old boy sustained a submersion injury at a pool party, and he had spontaneous return of respiration when rescued by adults at the party. However, 3 hours later, his parents bring him to the ED, as he is in respiratory distress. His pulse oximetry is 89%, and diffuse crackles and rales with retractions are noted on chest examination. His GCS score is 15 with a normal neurologic examination. You consider any diagnostics that may be necessary for this patient and what management should be undertaken...

A 2-year-old was pulled from a fast-moving river in Arizona during the spring by the swift-water rescue team after 45 minutes of submersion. She was apneic and pulseless when pulled from the river. She arrives to the ED after a 20-minute helicopter transport in full cardiorespiratory arrest, with CPR in progress. Her GCS score is 3, her pupils are fixed and dilated, and her rectal temperature is 34°C. When she is intubated, pulmonary edema is evident. Intraosseous access and central line access are obtained. While examining the patient, you consider your management options...

Introduction

Drowning and submersion injuries are leading causes of accidental death and injury in children in the United States and worldwide. Drowning accounts for > 500,000 deaths globally each year and is the leading cause of death worldwide among males aged 5 to 14 years.¹ In the United States, it is a leading cause of death in children aged 1 to 14 years. It is estimated that 80% of all drownings are preventable. The World Congress on Drowning defines drowning as “a process resulting in primary respiratory impairment from submersion/immersion in a liquid medium.” The victim may either live or die after the process but is still considered to be involved in a drowning incident.² Much of the earlier literature uses terms such as “near-drowning” to describe nonfatal drowning events. For example, many authors have defined “drowning” as any death within 24 hours of the event and “near-drowning” as any death that occurred after 24 hours. In an effort to come to a universal definition to aid in future research, in 2002, the World Health Organization (WHO) defined “fatal drowning” as

any death related to drowning and “nonfatal drowning” as those victims who survived. The use of terms such as “near-fatal drowning,” “near drowning,” or “secondary drowning” has been ill-defined and has led to confusion in the literature and difficulty in estimating the true number of drowning deaths and morbidity. Therefore, those terms should be abandoned in favor of the WHO definition. Much of the literature on pediatric drowning is devoted to defining the population of children who drown, prevention strategies, and defining physiological variables in children for whom aggressive resuscitation will result in a good neurological outcome. Although much of the resuscitation of the drowning pediatric victim is basic to all respiratory and cardiac arrest situations, there are some caveats for treatment of this type of injury.

Critical Appraisal Of The Literature

A literature search was performed using PubMed and Ovid MEDLINE® with the search terms *pediatric drowning, pediatric near drowning, pediatric submersion, prevention of pediatric drowning, hypothermia, and hypothermia and drowning*. Some adult drowning literature was also reviewed. Additional sources and information, such as safety guidelines from the American Academy of Pediatrics (AAP) (www.aappublications.org), information and statistics from the United States Centers for Disease Control and Prevention (CDC), the Consumer Product Safety Commission (CPSC) of the United States, Safe Kids Worldwide, and information from the World Congress on Drowning (www.cslsa.org/events/ArchiveAttachments/Spr03Minutes/AttachmentG2.pdf), were also accessed.

Much of the literature on drowning involves 4 topics: (1) the demographics of drowning, (2) resuscitation, (3) the outcomes of pediatric drowning victims, and (4) prevention. The demographic data are retrospective data analyses from national databases and organizations, such as the WHO. Resuscitation data include consensus statements from organizations (such as the International Liaison Committee on Resuscitation) and retrospective reviews.

Demographics Of Pediatric Drowning

According to CDC statistics from 2010, in the United States, drowning was the leading cause of accidents and deaths among children aged 1 to 4 years, the second leading cause in children aged 5 to 9 years, and the third leading cause in children aged 10 to 14 years.^{2,3} Similar statistics are mirrored in the drowning death rates in Australia and Europe.^{4,5} For low- and middle-income countries, the drowning rates for children are much higher, and children aged 1 to 3 years old are at the greatest risk.⁶

Difficulty in estimating the number of drowning-

related incidents and fatalities revolves around the lack of uniform reporting to government agencies and nationwide hospital databases of visits to the emergency department (ED) for drowning incidents.

The World Congress on Drowning published recommendations regarding the definition of drowning, treatment, and prevention in 2002. The final report, the Handbook on Drowning, was published in 2004.² Guidelines for the uniform reporting of data from drowning were recommended. Adopting the Utstein Style to report drowning incidences, the authors called for an abandonment of the terms “secondary drowning”, “near drowning,” and “wet versus dry drowning.” Other terms utilized are “submersion injuries” or “submersion incidents.” As a uniform Utstein style of drowning reporting is adopted by more institutes, future studies may yield more accurate data on drowning morbidity and mortality worldwide.

Drowning may further be defined by the type of water (eg, freshwater, saltwater) and the temperature. In general, warm-water drowning occurs in temperatures $\geq 20^{\circ}\text{C}$ (68°F). Cold-water drowning is defined as occurring in water temperatures $< 20^{\circ}\text{C}$ (68°F); however, this is sometimes defined as $< 15^{\circ}\text{C}$ or $< 10^{\circ}\text{C}$.

To aid in understanding how this very preventable cause of childhood death occurs, Brenner et al examined the site of drowning for all non-boating-related pediatric drowning in the United States.⁷ Using data from the CPSC in all 50 states, they reviewed 1420 drowning deaths. Freshwater drowning (drowning in lakes, rivers, and other natural bodies of water) accounted for 47% of drownings, followed by pools at 31%, bathtubs/buckets at 9%, saltwater drownings at 4%, and 8% of an unknown location. Among infants, 78% of drownings occurred at home. In children aged 1 to 4 years, the majority of drowning occurred in pools (55%) followed by freshwater locations. These percentages were roughly inverse for children aged 5 to 9 years in whom freshwater drowning accounted for the larger percentage. Freshwater remained the predominant drowning site in children aged 10 to 14 years and 15 to 19 years. In comparing site-specific drowning rates with regard to race, after age 5, drowning rates were significantly higher (12-15 times greater) among black males, especially in pool drowning. Drowning rates in Hispanic children were not discussed. Pool drowning was also described in terms of private versus public pools. A higher proportion of deaths in black children occurred in public pools.

Saluja et al further defined swimming pool drowning in the United States based on income levels and evaluated Hispanic children as well as black and Native American children.⁸ Hispanic children accounted for only 12% of the 738 drowning incidents that occurred between 1995 and 1998, and black children accounted for 47% of the incidents. Forty-

nine percent of the incidents occurred in low-income neighborhoods ($< \$35,400$), 29% in middle income neighborhoods ($\$35,400-\$48,000$), and 22% in high income neighborhoods ($> \$48,000$). With regard to pool locations, 37% occurred in public pools (including hotels/motels), 37% in residential pools, and 21% in neighborhood pools. Most pool drownings (77%) occurred between noon and 8:59 PM, and the highest proportion of these occurred between 3:00 PM and 6:00 PM. Saluja et al also noted that black children had the highest drowning rates, with a risk ratio of 5.5:12.1, and the risk was highest in males aged 15 to 19 years. This risk was noted to be independent of income. Black children were more likely to drown in public pools, Hispanic children in neighborhood/apartment pools, and white children in private/residential pools.

Similarly, statistics on drowning from the CDC from 2005 to 2009 concluded that black children have a higher drowning rate than white or Hispanic children.⁹ The rate of fatal drowning was highest for children aged < 4 years (2.55/100,000), and this age group also accounted for the most nonfatal drownings (52.8/100,000). Males were at a higher risk of a submersion incident than females. Swimming pools carried the highest rate of nonfatal drowning, and fatal drowning most often occurred in natural water locations. Most drowning incidents occurred on weekends, and June through August yielded the highest drowning rates. In addition, 5789 children are estimated to be treated annually in United States EDs, and 50% of these visits required hospitalization. Children aged < 4 years accounted for 53% of the ED visits related to submersion incidents.

Multiple other reports discussing the demographics of drowning deaths in Europe, New Zealand, and other developed countries reflect demographics among children similar to those in the United States. Australia also reports the highest rates of drowning deaths in children aged 0 to 4 years, and pool drowning in Australia occurs most often between 4:00 PM and 6:00 PM, during the summer months.¹⁰

Risk Factors For Pediatric Drowning

Many factors have been studied and determined to contribute to the risk of drowning. One well-studied risk factor for drowning is epilepsy. The risk of drowning for children with epilepsy is hypothesized to be ≥ 4 times that of children without epilepsy.^{11,12} In a population-based cohort study, children with epilepsy had a relative risk of 13.8 for drowning. Furthermore, children with epilepsy who had drowned tended to be older (aged > 5 years) than children without epilepsy who had drowned. Children with epilepsy aged > 5 years were at a significant risk for bathtub drowning compared to nonepileptic children, with a relative risk of 46.6 for a submersion

event and 95.6 for bathtub drowning.¹³ However, in this study and in a similarly sized population study from the United Kingdom, if they were supervised, epileptic children were at no greater risk for drowning deaths.¹⁴

Underlying cardiac dysrhythmias (such as congenital long QT syndrome and catecholaminergic polymorphic ventricular tachycardia) may also be a risk factor, especially in unexplained drowning in older children/adolescents. In a postmortem study of 35 victims of unexplained drowning incidents, nearly 30% of swimming-related drowning cases were positive for mutations associated with channelopathies. The mean age associated with these mutations and drowning deaths was 13.7 years. None of the 7 bathtub drownings were mutation-positive for long QT syndrome or catecholaminergic polymorphic ventricular tachycardia. All of the 8 mutation-positive victims had personal or family histories suggestive of underlying channelopathies, but none were diagnosed prior to their death.¹⁵ Brugada syndrome, catecholaminergic polymorphic ventricular tachycardia, and long QT syndrome have all been described to have swimming as a trigger for dysrhythmia.¹⁶ Hypertrophic obstructive cardiomyopathy may also contribute to drowning deaths in young males.^{17,18}

Hyperventilation prior to swimming may contribute to the risk of drowning. During initial hyperventilation, the partial pressure of carbon dioxide decreases, causing hypocapnia, which reduces the respiratory trigger to breathe, without increasing the partial pressure of oxygen. This can lead to syncope and the drowning incident. Hypoglycemia and hypothermia prior to submersion are 2 other factors that can contribute to drowning. Initial hypothermia (< 35°C prior to immersion) may cause muscular incoordination and weakness, which can interfere with swimming and any self-rescue attempts. This is usually seen when children fall through ice, becoming hypothermic and unable to self-rescue, prior to the actual drowning.

Other risk factors associated with drowning have less pertinence to young children, but they are worth mentioning in the case of adolescent drowning. Alcohol and illicit drugs have both been implicated as contributors to drowning. A number of studies suggest that persons with a blood alcohol level of 0.10 g/100 mL have > 10 times the risk of death from drowning.¹⁹

Pathophysiology

The Drowning Process

The “instinctive drowning response” has been described as a drowning victim being unable to wave or cry for help because breathing instinctively takes priority. Instead, the person is typically in an upright position with arms extended to the sides,

thrashing and slapping the water. The head may surface several times during this struggle, but the victim is unable to call for help. It is estimated that children can only struggle for 20 to 30 seconds before final submersion and that adults may be able to struggle for up to 60 seconds.²⁰

The drowning process begins when a person’s airway lies below the surface of a liquid medium, usually water.^{2,21} Water that has entered the oropharynx is either spat out or swallowed. Voluntary breath holding typically follows, but this lasts for approximately ≤ 1 minute.²² Small amounts of water are aspirated into the airway, triggering a coughing reflex and laryngospasm. During this time, the victim is unable to breathe and exchange gas, leading to hypoxia, hypercarbia, and acidosis.^{2,21} Multiple studies have shown significant alterations in arterial oxygenation when as little as 1 to 2.2 mL/kg of water are aspirated into the lungs.^{23,24} With a further decrease in arterial oxygen tension, laryngospasm abates and additional water is aspirated.^{2,20,21} Cerebral hypoxemia (rather than hypercarbia) quickly leads to loss of consciousness and apnea.²³ In the setting of asphyxia, cardiac deterioration quickly ensues. The entire drowning process usually takes place within seconds to minutes, but in special circumstances (such as hypothermia caused by drowning in ice water), the drowning process may last for an hour.²⁵

Pulmonary Factors

Intrapulmonary shunting of blood through poorly ventilated areas is the primary pathophysiologic process in drowning. This is due to multiple mechanisms, which may or may not be present, may vary in severity among individuals, and may occur initially or as a later finding in the person’s clinical course. Some of the mechanisms contributing to intrapulmonary shunting include bronchospasm, impaired alveolar-capillary gas exchange from aspirated fluid within the alveolar space, surfactant inactivation and washout, decreased surfactant production due to alveolar damage, and atelectasis. Aspiration of fluid and pulmonary edema contribute to ventilation/perfusion mismatch and cause a decrease in pulmonary compliance.²³ Infectious or chemical pneumonitis from aspiration of gastric contents may also occur, usually ≥ 24 hours after the drowning event.²⁶ Of note, there are no clinically significant differences in pulmonary injury between freshwater and saltwater drownings.

Cardiovascular Factors

Cardiac dysfunction and dysrhythmias are usually the consequence of hypoxia, acidosis, and/or hypothermia. The sequence of events is usually tachycardia followed by bradycardia, pulseless electrical activity, and finally asystole.¹ Ventricular fibrillation due to drowning is not as commonly observed,²⁷

but it may occur in the presence of hypothermia.²⁸ Additionally, significant hypovolemia and resultant hypotension may occur in hypothermic patients. During submersion in cold water, peripheral vasoconstriction directs blood to the core causing volume receptors to sense increased blood volume, leading to decreased production of antidiuretic hormone and a brisk diuresis.²⁹

Neurologic Factors

Permanent neurologic damage is not uncommon in those who have survived a significant drowning event. Neurologic outcome is determined by the duration and severity of the initial hypoxic-ischemic insult. Later in the clinical course, cerebral edema may develop, causing further compromise in tissue perfusion and brain injury.²⁹

Other Body Systems

Early animal studies have shown evidence of fluid shifts as a result of the difference in osmolarity of freshwater and saltwater, causing electrolyte abnormalities and fluctuations in hemoglobin and hematocrit.²³ However, retrospective studies have shown that victims who have survived a drowning event rarely aspirate quantities sufficient to cause these changes. Accordingly, these abnormalities are seen infrequently in clinical practice.^{23,29}

Metabolic acidosis is the most common and significant metabolic abnormality in a drowning victim. Renal insufficiency or failure is rare, but it can occur as a result of anoxia, shock, myoglobinuria, or hemoglobinuria.³⁰ Systemic inflammatory response syndrome, sepsis, and disseminated intravascular coagulation are possible complications usually occurring within the first 72 hours after resuscitation.²⁰

“Dry Drowning” – Does It Truly Exist?

Based on animal studies performed in the 1930s and 1940s, it was thought that approximately 10% to 15% of drowning victims die without significant entry of water into the lungs, termed “dry drowning.”³¹ The postmortem finding of “dry” lungs has been explained by various models, including the “laryngospasm” hypothesis, in which lethal hypoxia ensues secondary to reflex laryngospasm from fluid entering the nasopharyngeal and oropharyngeal airway. Additional explanations of dry drowning include mechanisms such as vasovagal cardiac inhibition or sudden cardiac arrest, pulmonary reflexes, and absorption of aspirated water into the bloodstream.³¹⁻³⁴

However, more recently, the issue of dry drowning has been questioned and reevaluated. While the “laryngospasm” hypothesis can be explained by the complex innervation and reflexes of the upper airway to various stimuli,^{35,36} there has been no concrete evidence that prolonged laryngospasm until death occurs during submersion. Rather, experimental data

has shown that initial breath holding and laryngospasm ends within 1.5 to 2 minutes after the onset of submersion.³⁷ Some authors have critically reviewed older experimental data and have questioned whether the diagnosis of drowning without aspiration is appropriate,³⁸ while others have altogether dismissed the idea of dry drowning as a myth without foundation.²⁰ Furthermore, a recent study has found that the actual incidence of death in persons found in water who have normal lungs or do not have penetration of liquid into their airways is much lower than previously thought (< 2%),³¹ lending support to the idea that dry drowning does not truly exist.

The Autonomic Conflict

Death in cold water has historically been attributed to hypothermia and drowning. However, in the past few decades, research has shown that cold water (< 15°C) submersion can induce a high incidence of cardiac dysrhythmias in healthy individuals. There are 2 conflicting and powerful autonomic processes that can occur during submersion in cold water while attempting breath-holding: (1) the cold shock response, and (2) the diving response.³⁴

The cold shock response is a reflex stimulated by cutaneous cold thermoreceptors, causing sympathetically mediated tachycardia, a respiratory gasp, uncontrollable hyperventilation, peripheral vasoconstriction, and hypertension.³⁹ Alternatively, the diving response is characterized by profound sinus bradycardia driven by excitation of cardiac vagal motor neurons. Expiratory apnea and peripheral vasoconstriction also occur and are driven by the reflex inhibition of the central respiratory neurons and excitation of the sympathetic vasoconstrictor neurons, respectively. The primary function of the diving response is to conserve oxygen and extend underwater time.³⁴

The diving response has been observed in all the marine and terrestrial vertebrates that have been studied thus far. However, in humans, the diving bradycardia and vasoconstriction is attenuated and slower to develop than in diving mammals.⁴⁰ Dysrhythmias are rarely observed in diving mammals, as they possess a strong diving response and may lack a significant cold shock response. However, it is hypothesized that, in humans, a combination of the 2 responses may cause an autonomic conflict and subsequently a higher incidence of dysrhythmias during cold water immersion.³⁴

Differential Diagnosis

Predisposing medical conditions, such as hypoglycemia, seizures, drug ingestion and alcohol intoxication, and cardiac dysrhythmias (including long QT syndrome) must be considered in the differential. It has been found that epilepsy increases the risk of

drowning 4- to 14-fold in children.^{11-15,29,41-44} Other predisposing events (such as concomitant traumatic injury to the head, cervical spine, or other organs) should be considered, but these may not always be evident due to hypothermia and altered mental status. Nonaccidental trauma should be considered in the differential diagnosis of a bathtub submersion victim who presents with inconsistent histories from the caregivers, a previous history of abuse, late presentation for medical care, and/or physical findings common to other forms of abuse.^{42,45}

Prehospital Care

Clinical outcome in the drowning victim is ultimately determined by the extent of hypoxic insult. Since time is a critical element, bystander rescue and immediate initiation of resuscitation is imperative. Some studies have shown survival only in those persons who received bystander resuscitation.^{46,47}

The main objective of prehospital therapy is to restore normal ventilation and circulation as quickly as possible. Initial evaluation should include assessment of airway, breathing, and circulation. If there is no response, the person should be assumed to be in cardiac arrest and should be removed from the water immediately. Emergency medical services (EMS) should be activated, and the victim should be carefully assessed for the presence of a pulse. Severe bradycardia due to hypoxia, hypothermia, and/or vasoconstriction may make it difficult to palpate an arterial pulse. Chest compressions should be initiated if there is any question about the existence of a pulse, and mouth-to-mouth ventilation should be continued until further help arrives.²³

If the victim is apneic, initial efforts should be focused on opening the airway and delivering rescue breaths and should be performed by a highly trained rescuer (such as a lifeguard). Ideally, this is begun in the water if it can be done without putting the rescuer in danger.²⁰ Drowning victims with only respiratory arrest usually respond after a few rescue breaths.¹

If the rescuer is a layperson, he or she should open the airway, check for breathing, and deliver rescue breaths if there is no spontaneous breathing. After delivery of effective rescue breaths, the lay rescuer should immediately begin chest compressions. If available, and a shockable rhythm is identified, an automated external defibrillator should be placed, and the rescuer should attempt defibrillation.

Since cardiac arrest from drowning is primarily due to the lack of oxygen, it is important that cardiopulmonary resuscitation (CPR) follow the traditional sequence of airway-breathing-circulation, rather than circulation-airway-breathing.^{1,48} While the American Heart Association continues to recommend 2 rescue breaths,⁴⁸ the European Resuscitation Council recommends 5 initial rescue breaths in cases

of drowning, since initial ventilations can be more difficult to achieve due to water in the airway interfering with effective alveolar expansion.^{1,49}

Once more extensively trained personnel and equipment is available, other therapeutic modalities should be considered. Ventilation with a bag-valve-mask device and 100% oxygen should be initiated as soon as it is available. An endotracheal tube should be placed to obtain an airway and to facilitate mechanical ventilation and oxygenation in patients who are unconscious or unable to protect their airway.

During resuscitation, care must be taken to avoid hyperextension of the neck in patients with suspected cervical spine injuries, especially in cases in which trauma is suspected. Instead, the jaw-thrust maneuver should be performed. Routine immobilization of the cervical spine is not warranted based solely on the history of submersion. As demonstrated in a study by Watson et al, cervical spine injuries occur in < 0.5% of drowning events, and they are unlikely in low-impact submersions (such as swimming and bathing).⁵⁰ Cervical spine immobilization is indicated only in cases where trauma to the head and neck is highly suspected (such as in incidents sustained while diving, surfing, or water skiing, or from a boat or motor vehicle collision resulting in drowning).

The most frequent complication of resuscitation in drowning victims is regurgitation and aspiration of stomach contents. It has been estimated that > 65% of persons receiving rescue breathing alone and 86% of victims requiring CPR regurgitate gastric contents.⁵¹ The presence of vomitus in the airway often leads to further pulmonary injury and impairment of oxygenation. A thorough review by the Institute of Medicine concluded that it is inappropriate to use the Heimlich maneuver (or back blows/chest thrusts in infants) when treating drowning victims unless a foreign object is seen obstructing the airway.⁵² Compressions aimed at removing fluid from the lungs have not been proven to be effective and, instead, delay the start of resuscitation, greatly increasing the risk of vomiting and aspiration.

A large-bore peripheral intravenous catheter is the preferred route for drug administration in the prehospital setting, with intraosseous access as an alternative. Endotracheal administration of drugs is not recommended.¹ If hypotension is not corrected by ventilation and oxygenation, then rapid crystalloid infusion (0.9% saline solution) should be administered regardless of whether saltwater or freshwater has been aspirated.⁵³ Drug therapy (eg, epinephrine) and defibrillation should be administered as indicated per Neonatal Resuscitation Program, Pediatric Advanced Life Support, and Advanced Cardiac Life Support guidelines.

All patients (no matter how well appearing) must be taken to a hospital for evaluation, given that the initial appearance of a drowned victim may be

misleading. Transport by EMS should involve basic monitoring of respiratory rate and pattern, pulse, blood pressure, and pulse oximetry. Oxygen should be administered en route and continued until it can be reduced safely, with maintenance of hemoglobin-oxygen saturation in the mid to high 90s.²³ In hypothermic drowning victims, wet, cold clothing should be removed, and passive rewarming measures should be initiated.

Emergency Department Evaluation

A drowning victim may present to the ED in a variety of clinical states, ranging from seemingly asymptomatic to full cardiac arrest. If possible, a history should be obtained from the parents or EMS, including circumstances leading to the drowning event, time of immersion, length and degree of resuscitation at the scene and in the field, and preexisting medical conditions.

In the ED, the patient's airway, breathing, and circulation should be reevaluated. Additionally, the need for cervical spine immobilization (based on history and/or signs of trauma to the head and neck) should be determined. The initial physical examination should include assessment of the patient's level of consciousness, cardiac and pulmonary examination, acquisition of body temperature to evaluate for hypothermia, and examination for physical signs of trauma to the chest and abdomen. Secondary and serial examinations should be more focused, based on the initial examination findings.

Diagnostic Testing

All drowning victims should be presumed to be hypoxic and, at a minimum, need continuous pulse oximetry monitoring. Minimal laboratory and radiographic studies are needed for drowning victims who are alert, breathing spontaneously, and without respiratory symptoms. Evaluation of a more symptomatic patient may include blood glucose level, arterial blood gas level, complete blood count, electrolytes levels, chest radiography, and cardiorespiratory monitoring with pulse oximetry and a rhythm strip. Although electrolyte and hematocrit levels are rarely abnormal regardless of water type (freshwater vs saltwater),²⁰ patients who are hypothermic or who have sustained a significant hypoxic event should have baseline potassium and renal and hematologic functions measured. Also, consider obtaining coagulation studies and creatine kinase in a severely hypothermic or critically ill child. Toxicological screening for alcohol or drug ingestion may be warranted in preadolescent and adolescent victims. Lastly, patients with known or suspected blunt trauma (head, neck, or multisystem) will require

additional laboratory and radiographic imaging studies as part of their trauma assessment.

Treatment

The first priority in managing drowning victims in the ED is to reverse hypoxemia by restoring adequate oxygenation and ventilation. As previously discussed, initial efforts should focus on airway, breathing, and circulation. Oxygen, with or without mechanical ventilation support, is the first line of therapy. Patients who are breathing spontaneously and are able to maintain an oxygen saturation > 90% or a partial pressure of oxygen > 90 mm Hg with a fraction of inspired oxygen of 0.5 may need oxygen therapy alone.²⁰

Drowning victims who are apneic or have respiratory compromise are best managed with tracheal intubation using a rapid sequence induction technique. Intubation not only secures an airway but also protects against aspiration of gastric contents and allows for suctioning of the airway and effective oxygenation and ventilation through copious pulmonary edema. Mechanical ventilation with positive end-expiratory pressure should be used.²⁰

Both freshwater and saltwater drowning victims with evidence of shock need aggressive intravenous fluid resuscitation with a crystalloid solution (such as normal saline). Initial fluid boluses of 20 mL/kg are appropriate. If intravenous access cannot be obtained in a timely manner due to ongoing CPR or extreme vasoconstriction, intraosseous access should be considered.⁴⁷

Cardiac dysfunction (characterized by decreased cardiac output and high systemic and pulmonary vascular resistance) may occur secondary to hypoxia associated with drowning. This injury may persist even after adequate oxygenation, ventilation, and perfusion have been established. Thus, a cardiogenic component may be added to the noncardiogenic pulmonary edema already present.⁴⁷ In these cases, furosemide is not usually indicated. However, inotropic agents (such as dobutamine) may be necessary to improve cardiac output and reestablish adequate tissue perfusion.²⁰

Acidosis is typically corrected with restoration of adequate oxygenation and ventilation as well as through circulatory volume expansion and inotropic agents. Sodium bicarbonate administration is usually unnecessary.⁵⁴ It should be noted that steroids are ineffective, and they may worsen outcome by interfering with the normal healing process.

Management Of Hypothermia

Hypothermia is defined as a core temperature < 35°C and should be presumed and treated in all drowning victims, including warm-water drownings. This condition can occur even in warm water or pool

drowning incidents during the summer months, due to exposure during the rescue phase and further evaporation losses during transport.

The main goals in the management of hypothermia are to prevent further decline in core temperature and to establish a safe and steady rewarming rate while maintaining cardiovascular stability. Core temperature (rectal) should be taken on arrival to the ED. Since standard clinical thermometers often do not measure temperatures < 34°C (94°F), access to a thermometer able to read lower temperatures is recommended for use in children, particularly in an arrest situation. Esophageal thermometers are likely to be the most accurate reflection of core temperature, but they may not always be available. Alternatively, bladder or rectal low-reading thermometers should be made available. Methods of rewarming are outlined in **Table 1**.

External Rewarming

In mild hypothermia (32°C-35°C), passive rewarming is usually sufficient. This involves removal of wet, cold clothing and using warm blankets to insulate the patient. In patients with moderate (28°C-32°C) or severe hypothermia (< 28°C), active internal and/or active external rewarming should be used. Active external rewarming may be achieved with hot packs (40°C) and heat lamps. Care must be taken to avoid iatrogenic burns. Additionally, these techniques should be applied primarily to the trunk and not the extremities in an effort to avoid an “afterdrop” in core body temperature secondary to cold blood from the periphery recirculating centrally.⁴⁷ Forced rewarming, a method which blows heated air onto the patient through inflated tubes or blankets has also been shown to be effective.^{55,56}

Internal Rewarming

Active internal rewarming measures include warmed humidified oxygen via mask or endotracheal tube, warmed intravenous fluids (40°C-44°C)

Table 1. Methods Of Rewarming A Hypothermic Patient After A Submersion Incident

Passive external rewarming

- Remove wet clothing
- Insulate with warm blankets/forced air warming blankets

Active external rewarming

- Hot packs and heat lamps to trunk of body only
- Heated air blower

Active internal rewarming (if core temperature ≤ 30°C)

- Warmed intravenous fluids (40°C-44°C)
- Warmed humidified oxygen (42°C-46°C)
- Peritoneal lavage (potassium chloride free fluid)
- Thoracic lavage with intravenous fluids (39°C-41°C)

using the shortest possible length of intravenous tubing, and warm saline lavage (thoracic,⁵⁷ gastric, peritoneal, rectal, and mediastinal lavage).⁴⁷ Extracorporeal rewarming can be considered for victims with profound hypothermia or cardiac arrest in the context of rapid immersion in cold water.

Thoracic lavage may seem a more extreme (yet effective) method of active internal rewarming accomplished by either tube thoracotomy (closed) or thoracotomy (open). In the closed thoracotomy, 2 chest tubes are placed in each hemithorax and sterile saline at 39°C to 41°C is infused by gravity into the superiorly placed tube and drains passively through the inferiorly placed tube. In a review of the literature on this method of rewarming, 13 previously published cases using tube thoracotomy were reviewed, including 1 case involving an 8-year-old drowning victim who recovered.⁵⁷ The median rewarming rate was 2.95°C per hour, with a median time until sinus rhythm return of 120 minutes. Care should be taken to ensure adequate drainage, and in the closed method, irrigation is continuous with no dwell time. High-flow intravenous fluid warmers offer the best continuous supply of these fluids.⁵⁸

The goal should be to rewarm the patient 1°C to 2°C per hour to a range of 33°C to 36°C.⁵⁹ If the patient is hemodynamically stable, aggressive rewarming above this range should be avoided. Hyperthermia has been shown to worsen underlying cerebral injury in post-cardiac arrest patients.⁶⁰ Core temperature should be monitored continuously with a deep rectal or esophageal probe.

In cases of severe hypothermia (< 30°C), most drowning victims become apneic and develop sudden cardiac arrest. While initial rewarming and resuscitation are underway, the emergency clinician should consider active external rewarming with extracorporeal membrane oxygenation (ECMO) or cardiopulmonary bypass (CPB). This provides the most rapid effective core rewarming, especially in hypothermic drowning patients with asystole or ventricular fibrillation. Preplanned protocols have been shown to be important to avoid time lost in these situations.⁶¹

Although there is controversy with the old adage “No one is dead until they are warm and dead,” most would agree that rewarming should continue until core temperature reaches between 32°C and 34°C. If asystole persists after this, consideration should be given to terminating resuscitation efforts, depending upon the individual circumstances.

Other Physiological Considerations For Hypothermia

Other physiological considerations vary in management of the hypothermic patient versus the normothermic patient. Hypothermic patients are usually hypovolemic; thus, fluid resuscitation is essential. They may also have either hypercoagulability or

hypocoagulability. Rhabdomyolysis may occur, but this is usually seen later in the hospital course. Hypoglycemia, hyperkalemia, and hypophosphatemia should be assessed and corrected, if needed. Since acidosis is primarily respiratory in origin, limited correction with sodium bicarbonate is advised.

Profoundly hypothermic patients often have no vital signs. The European Resuscitation Council recently put forth guidelines recommending a modified approach to advanced life support. It was suggested that only 3 defibrillations be performed, and epinephrine should be withheld until core temperature is $> 30^{\circ}\text{C}$ (86°F). It was also recommended that the time between epinephrine doses be doubled until the core temperature is $> 35^{\circ}\text{C}$ (95°F).⁴⁴ The American Heart Association is less certain in their recommendations for defibrillation, recommending at least 1 shock for ventricular tachycardia/ventricular fibrillation and that further shocks follow the Advanced Cardiac Life Support protocol, although there is only class C evidence to support this.⁴⁴ Likewise, at least 1 dose of medication (epinephrine or vasopressin) should be given, and subsequent doses should be given as per the Advanced Cardiac Life Support protocol. Again, high-quality evidence does not exist for these recommendations.

Referral To The Intensive Care Unit

The emergency clinician should recognize when a patient should be referred to the pediatric intensive care unit (PICU) and should be aware of the management options that are available while patients are awaiting admission or transfer to the PICU. Important supportive measures for drowning victims in the ICU include nasogastric tube placement to prevent further aspiration and Foley catheter placement to monitor strict urine output. Although renal insufficiency or failure is a rare occurrence in drowning victims, these may occur secondary to anoxia, shock, or hemoglobinuria.

Acute respiratory distress syndrome (ARDS) is common after a significant drowning event. The management of drowning victims with ARDS is similar to that of other patients with ARDS, including utilizing measures to minimize barotrauma. However, ventilation strategies for the patient with acute lung injury (such as permissive hypercapnia) may not be suitable for drowning victims with significant hypoxic-ischemic brain injury, in which normocapnia or mild hypocapnia is often desired.^{20,59} In order to permit adequate surfactant regeneration, weaning from mechanical ventilation should not be initiated for at least 24 hours even when gas exchange appears to be adequate, and this should be addressed in the ICU.²⁰ Additionally, local pulmonary injury may not have resolved sufficiently, and pulmonary edema may reoccur necessitating reintubation.¹ Furthermore, the fraction of inspired oxygen should be decreased to ≤ 0.5 as soon as possible to

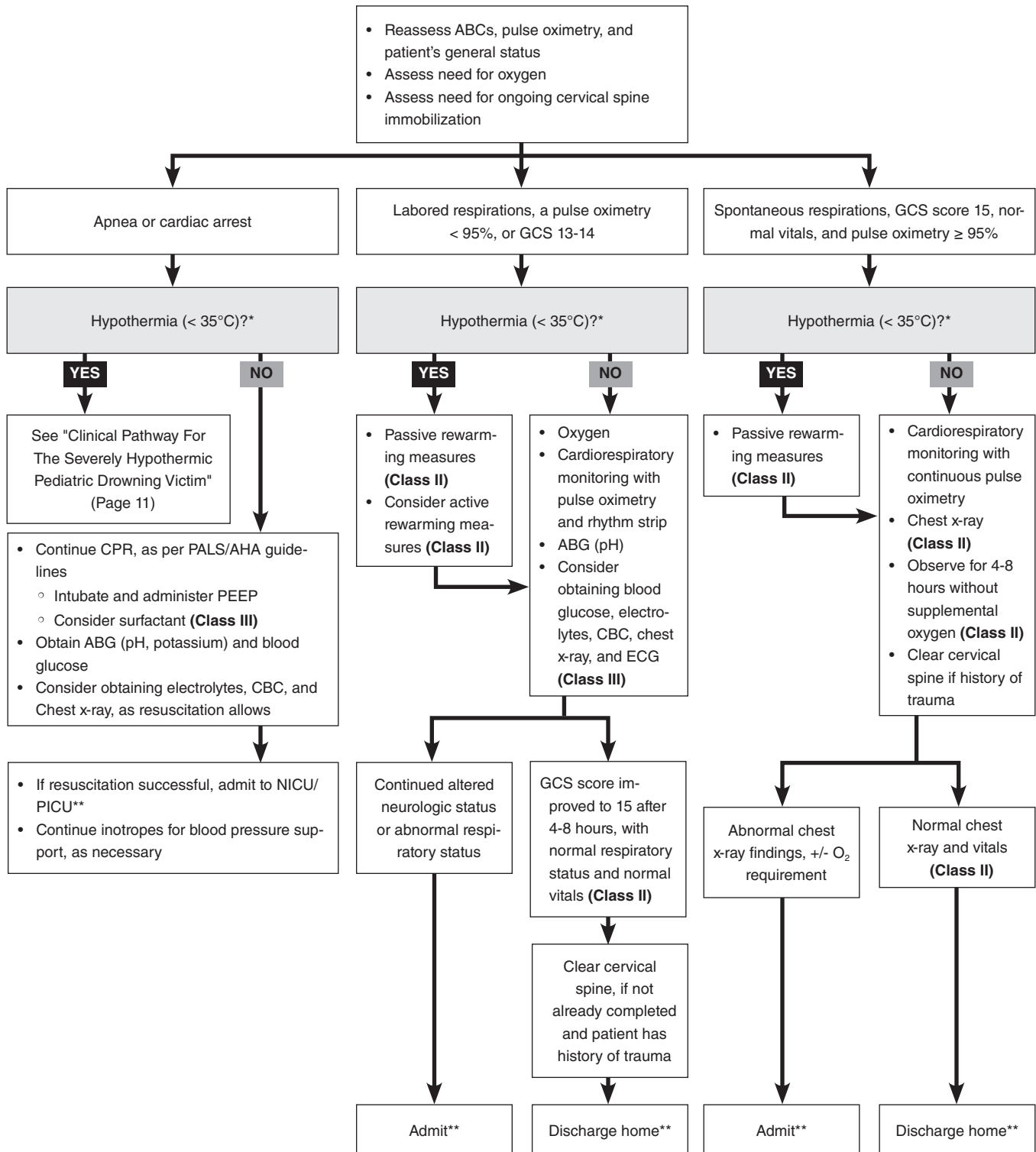
avoid increased pulmonary injury through oxygen toxicity.²⁰ Corticosteroid therapy has generally been shown to be ineffective in reducing the pulmonary injury caused by drowning, and it may worsen the outcome by interfering with the normal healing process.^{1,23} There are some case reports documenting successful use of exogenous surfactant to treat lung injury associated with pediatric drowning.⁶²⁻⁶⁵ However, use of this treatment should be limited. Pneumonia in drowning victims typically develops after the first 24 hours, so it will be a management concern in the ICU rather than the ED. Nonetheless, the use of prophylactic antibiotics has not been shown to be beneficial,²⁶ and it should be reserved for when and if the patient develops signs of infection.

Aside from pulmonary injury, the most significant and important complication of drowning is the anoxic-ischemic cerebral insult. Most late deaths and long-term sequelae in hospitalized drowning victims are neurologic in origin.⁴⁷ Monitoring for the development of cerebral edema should take place in the ICU setting, and the emergency clinician should recognize the need for referral in these situations. Efforts should be made to resuscitate the brain and prevent further neurologic damage early in management of these patients. This includes prevention of hypoxia, hypercapnia, and hyperthermia, all known to worsen neurologic damage.⁶⁰ While barbiturate coma, neuromuscular blockade, hyperventilation, and mannitol for treatment of elevated intracranial pressure have failed to improve the outcome of severely comatose drowning victims,^{20,23} the clinician may consider induced hypothermia.^{63,66,67}

Disposition

While the epidemiology, pathophysiology, prognostic indicators, treatment modalities, and preventive measures of drowning have been well studied, there is limited literature addressing the management and disposition of asymptomatic and mildly symptomatic drowning victims. Given the concern of "secondary drowning," in which there is respiratory and clinical deterioration in a seemingly well patient, some authors have recommended admission for all drowning victims.^{68,69} However, more recent studies by Noonan et al and Causey et al have demonstrated that routine admission is unnecessary.^{70,71} Based on the results presented in the literature, most authors recommend that moderate to severely symptomatic children be initially stabilized in the ED and promptly admitted to an ICU or inpatient unit.⁷⁰⁻⁷³ All other children should receive a full medical evaluation in the ED and be observed for a 4- to 8-hour period. Asymptomatic children who do not develop symptoms and mildly symptomatic children who return to normal during the observation period can be discharged home if follow-up can be assured. Pa-

Clinical Pathway For Pediatric Drowning Victims



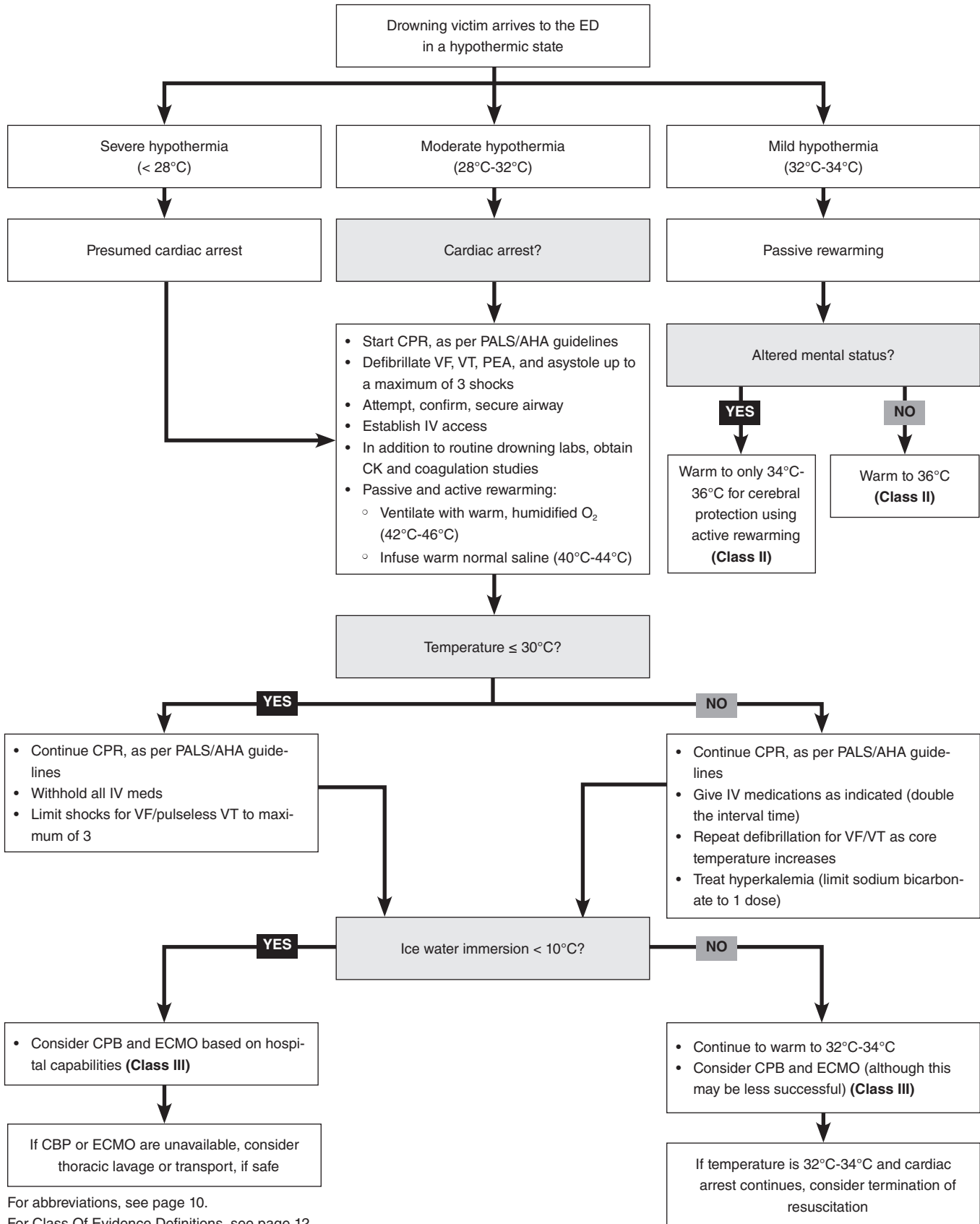
*Confirm core temperature with rectal thermometer if oral/axillary temperature is < 35°C.

**Consider social work consult for all drowning victims who present to the ED.

Abbreviations: ABCs, airway, breathing, and circulation; ABG, arterial blood gases; AHA, American Heart Association; CBC, complete blood count; CK, creatine kinase; CPB, cardiopulmonary bypass; CPR, cardiopulmonary resuscitation; ECG, electrocardiogram; ECMO, extracorporeal membrane oxygenation; ED, emergency department; GCS, Glasgow Coma Scale; IV, intravenous; O₂, oxygen; PALS, pediatric advanced life support; PEA, pulseless electrical activity; PEEP, positive end-expiratory pressure; NICU, neonatal intensive care unit; PICU, pediatric intensive care unit; VF, ventricular fibrillation; VT, ventricular tachycardia.

For Class Of Evidence Definitions, see page 12.

Clinical Pathway For The Severely Hypothermic Pediatric Drowning Victims



For abbreviations, see page 10.

For Class Of Evidence Definitions, see page 12.

tients who clinically deteriorate or remain symptomatic (ie, abnormal vital signs, labored respirations, oxygen requirement, altered level of consciousness) after 8 hours of observation should be admitted to the appropriate inpatient facility.

Predictors Of Outcomes In The Pediatric Drowning Patient

One of the most difficult decisions that challenges the emergency clinician is determining when resuscitative efforts may be successful and when efforts may be futile. Accurate prediction of a neurologically good or poor outcome is essential for guiding clinical decision making. Some of these decisions will be made in the ED, some much later in the ICU. Unfortunately, the quality of information regarding a specific drowning event, especially true submersion time and quality of resuscitation efforts in the field, may be lacking in the immediate moments upon arrival to the ED. Most of the studies focused on predictors of good versus poor neurologic outcome are single-institution studies with small numbers. To date, no multicenter studies addressing factors which may predict pediatric drowning outcomes have been performed.

Two early studies in the 1970s retrospectively examined pediatric drowning outcomes and resuscitation in the field. In the first study, charts of 72 drowning victims requiring resuscitation in the field were reviewed.⁷⁴ Fifteen of the patients also required CPR in the ED and, despite return of circulation within minutes, demonstrated moderate to severe anoxic encephalopathy. The authors concluded that the utility of CPR in the ED needed to be reevaluated. However, important details about submersion time, body pH, and sequential neurologic examinations in the PICU were missing. In 1979, Pearn et al looked at the neurologic sequelae of 104 pediatric drownings in Hawaii.⁷⁵ Of note, children with no heart rate on rescue were declared dead on the scene

and were not included in the study. Seventy-five children were apneic and unconscious on initial rescue but had a heart rate. Among these, 70 were discharged from the hospital without neurological deficit. Again, no mention was made regarding submersion time and the degree of resuscitation in the ED. In 1979, Orłowski established a prognosis score with 5 indicators based on his studies: age < 3 years, submersion time > 5 minutes, resuscitation delayed for > 10 minutes, coma on hospital admission, and initial pH of < 7.1. Children with ≥ 3 indicators would have been expected to have a mortality rate of at least 90%.⁷⁶

Resuscitation In The Field And Cardiopulmonary Resuscitation Duration

Two studies, both from the University of Washington, sought to better define predictors of drowning outcomes.

In the first of these, characteristics of 38 pediatric victims who had cardiovascular arrest and received Advanced Cardiac Life Support in the field were reviewed.⁷⁷ Of the 38 patients who had cardiac arrest in the field, 63% made a good recovery. Factors with the highest risk for a poor outcome included: CPR for > 25 minutes (100% risk), submersion for > 25 minutes (100% risk), submersion between 10 and 25 minutes (88% risk), and an initial heart rhythm of ventricular tachycardia or fibrillation (92% risk). These factors were all ascertained in the prehospital phase of care. Using logistic regression, electrocardiography, and vital signs, it was determined that the use of pupillary reactivity or mental status, either alone or in combination, could not improve the ability to predict outcomes. The strongest predictors were submersion time and CPR duration. The authors concluded that aggressive prehospital care offered the best chance of survival for pediatric submersion injuries.

The later study also looked at prehospital prognostic indicators in 77 patients.⁷⁸ The study found that the 29 pediatric patients who experienced cardiac

Class Of Evidence Definitions

Each action in the clinical pathway section of *Pediatric Emergency Medicine Practice* receives a score based on the following definitions.

Class I

- Always acceptable, safe
- Definitely useful
- Proven in both efficacy and effectiveness

Level of Evidence:

- One or more large prospective studies are present (with rare exceptions)
- High-quality meta-analyses
- Study results consistently positive and compelling

Class II

- Safe, acceptable
- Probably useful

Level of Evidence:

- Generally higher levels of evidence
- Non-randomized or retrospective studies: historic, cohort, or case control studies
- Less robust randomized controlled trials
- Results consistently positive

Class III

- May be acceptable
- Possibly useful
- Considered optional or alternative treatments

Level of Evidence:

- Generally lower or intermediate levels of evidence
- Case series, animal studies, consensus panels
- Occasionally positive results

Indeterminate

- Continuing area of research
- No recommendations until further research

Level of Evidence:

- Evidence not available
- Higher studies in progress
- Results inconsistent, contradictory
- Results not compelling

This clinical pathway is intended to supplement, rather than substitute for, professional judgment and may be changed depending upon a patient's individual needs. Failure to comply with this pathway does not represent a breach of the standard of care.

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arrest were more likely to have > 25 minutes submersion time. Of the 29 patients in cardiac arrest, 16 had no return of spontaneous circulation (ROSC) and died in the ED or in the field. In another 13 patients, ROSC was achieved; however, only 6 later survived, and 4 were severely neurologically impaired.

Comparing patients in both studies, predictors of children with either mild or no neurologic impairment included a submersion time \leq 5 minutes (91%) and a resuscitation duration \leq 10 minutes (87%). Conversely, indicators of death and severe neurologic impairment with cohorts from both studies combined included resuscitation duration > 25 minutes and a submersion time > 25 minutes. The gray area is a resuscitation duration between 11 and 25 minutes (68% death or poor outcome) and a 10- to 25-minute submersion time (90% death or poor outcome).

Resuscitation efforts and outcomes in 166 children (with a mean age of 35.6 months) were analyzed in a case control study between 1984 and 1992.⁷⁹ All children experienced a submersion event resulting in apnea or altered respirations. The study found that any type of resuscitation was related to a good outcome; however, the best outcome was achieved in children receiving CPR. Heart rate (present or absent) in the field was not analyzed, nor was patient condition on arrival to the ED. Submersion times of > 10 minutes had a poor prognosis (62.5%), and hypothermia (< 33°C) was strongly associated with a poor clinical outcome (69.3% of 27 patients), especially when combined with prolonged submersion time > 10 minutes (75% of 8 patients). It is important to note that because this study was performed in Southern California, the hypothermic patients were rescued from non-icy waters (> 20°C).

Glasgow Coma Scale Score And Pediatric Risk Of Mortality Score

A study group from Southern California reviewed the charts of 274 pediatric submersion patients to determine if survivors could reliably be identified.⁸⁰ Good neurologic outcome patients were divided into 2 groups: intact (return to full function predicted) and unpredictable good outcome. The unpredictable good outcome patients were patients who survived intact who, based on factors (such as arrest and submersion time), would otherwise have been predicted to be in vegetative or dead. The mean age of the patients was 32 months. Of the 274 patients, 71 were in cardiac arrest, and 13 had pulseless electrical activity, 125 were intubated, and 89 received CPR in the ED. The longest CPR duration of an intact survivor was 47 minutes. Of 100 patients with an initial Glasgow Coma Scale (GCS) score of 3, 14 survived intact. Of 165 patients with a GCS score of \geq 4 on ED arrival, only 2 survived in a vegetative state and the rest survived neurologically intact. When looking at intact survivors, all except 1 demonstrated func-

tional recovery within 48 hours. A combination of 3 variables (CPR in the ED, apnea and coma in the ED, and a pH < 7.0) predicted most of those with a poor outcome (93%). The authors concluded that an "intermediate approach," which begins with aggressive treatment of all pediatric drowning victims but supports termination of therapy after 48 hours of ICU treatment if no neurologic improvement is detected, should be utilized.

Other studies provide an additional way to assess this difficult clinical situation by looking at PRISM (Pediatric Risk of Mortality) scores. The PRISM score (1988) consists of 14 variables weighted with different scores (including vital signs, GCS score, pupillary reactions, and laboratory values) to scale the relative severity of disease and, therefore, the risk of mortality. In a retrospective chart review of 81 pediatric drowning patients admitted to the PICU between 1976 and 1992, the GCS and PRISM score were used.⁸¹ The median age of these patients was 40.7 months; 96% had CPR on scene. Approximately half of the patients died and half survived, 26 with a good outcome. A PRISM score of \geq 20 on initial evaluation in the PICU predicted poor outcome (97.1%), and a GCS score \leq 4 also predicted poor outcome (100%). In addition, asystole in the ED also predicted poor outcomes of death or complete dependence in 49 patients. Of the 44 patients with a PRISM score \geq 20, 38 died. Aggressive therapeutic intervention (such as continuous intracranial pressure monitoring and management of intracranial hypertension) did not improve outcomes. Another study of 60 patients over a 22-year period concluded that a PRISM score < 16 was predictive of patients who would survive without impairment. Patients with a PRISM score \geq 24 either survived with serious neurologic impairment or died.⁸² The group of patients with PRISM scores of 17 to 23 corresponded to an intermediate group, with the probability of death between 16% and 42%. Therefore, there were no clear predictive values in patients with these PRISM scores.

State Of Hypothermia

Although a study by Kyriacou et al in 1994 found that children who had arrived hypothermic (< 33°C) to the ED did not have good outcomes,⁷⁹ Biggart and Bohn retrospectively reviewed 55 drowning victims and obtained different results.⁸³ Twenty-two children were submerged in cold water, 33 in warm water (no definitions of water temperatures were given); 37 children survived to hospital arrival. With all other factors equivalent for a subset of 27 patients with absent vital signs, GCS score of 3, and prolonged CPR in the ED, 4 of 14 patients with an initial temperature of < 33°C survived neurologically intact, whereas 0 of 13 patients with temperatures \geq 33°C survived neurologically intact. However,

length of time of submersion was not discussed in this paper. The authors concluded that the most important determinates of neurologically intact survival were the presence of a pulse in the ED and hypothermia.

Water Temperature

Additional studies have examined whether water temperature is a factor in predicting pediatric drowning outcome. One study of children aged < 16 years retrospectively examined 48 children with a mean age of 3.7 years who received basic and advanced life support on the scene.⁸⁴ Thirty-one survived, and 29 of those patients (59% of the total) survived with good neurologic outcome. The authors created a Near Drowning Severity Index (NDSI) to measure the effects of water and body temperature on survival. They concluded that rapid development of hypothermia in children with a larger body surface area did not add protection against a poor outcome. At a 10-minute submersion time, the NDSI was a good predictor of outcome. In a second study, 61 drowning victims (43% were children, with a median age of 4.4 years) were examined to look for any effect of water and body temperatures on outcomes.⁸⁵ Forty-seven patients had a rectal temperature < 35°C, and the median water temperature was recorded as 17°C. The surviving patients had a median submersion time of 10 minutes (range of 1-38 minutes), and 4 neurologically intact survivors had a median submersion time of 5 minutes (range of 1-21 minutes). In those who died, the median submersion time was 15 minutes. Submersion time was the only independent predictor ($P < 0.01$), yet a clear cutoff value below which survival could be predicted could not be determined. Temperature did not affect outcome, and children did not have better outcomes than adults. An immediate temperature of 17°C is considered by most to be cold water; ice-cold water is usually defined as either < 5°C or < 10°C.

A recent study looked retrospectively at the role of water temperature in outcomes of adult and pediatric drowning victims over a period from 1974 to 1996. Some of this data was analyzed earlier in a previously published study.^{86,87} Out of 1094 victims (with a mean age of 27 years), there were no differences in survivors with good neurologic outcome regardless of water temperature (22% had a good outcome). Patients with good outcomes were more likely to be young (< 15 years), female, and have a submersion time of < 6 minutes at water temperatures > 16°C.⁷⁶

Age Of Drowning Victim

Previously, children were considered to be more likely to survive an out-of-hospital cardiac arrest. A prospective observational study conducted in Japan in 2013 compared adult versus child drowning

victims.⁸⁸ The major endpoints of this study were 1-month survival and favorable neurologic outcome. Pediatric drowning patients were divided into age groups of 0 to 4 years and 5 to 17 years and compared to adults. Younger children were more likely to achieve ROSC than older children, but there was no difference in the 1-month survival or in favorable neurologic outcome between the 2 groups. Children were more likely to survive at 1 month than adults, but only 34% of pediatric survivors had a favorable neurologic outcome at 1 month. More children received bystander CPR than adults, which may account for some of the improved outcome between the groups.

Other Predictors

Apart from submersion time, duration of CPR before ROSC, GCS score on ED arrival, and time to return to neurologic function, no other good prognostic indicators exist to predict pediatric drowning outcomes. Many studies have looked at laboratory values (such as pH or potassium levels) and have concluded that a pH < 7.0 or significantly elevated potassium levels may indicate poor outcome, but none of the patient numbers have been large enough to determine any conclusive results. Finding an early laboratory marker that could predict outcome in these pediatric drowning victims would be beneficial. A small study of 9 pediatric patients (mean age of 3.8 years) prospectively looked at cardiac troponin as a possible predictor of mortality in drowning pediatric patients.⁸⁹ The mean troponin I level of survivors was lower than nonsurvivors, although this did not reach statistical significance. Larger numbers and possibly the measurement of troponin I in children who present, not only to the PICU, but also to the ED, may have yielded more significant results. Future research into predicting the outcomes of pediatric drowning victims clearly needs to include a search for rapid serum markers which may aid in the resuscitation process.

Bottom Line

Most patients with a heart rate on arrival to the ED (but who are apneic on rescue, have a submersion time < 10 minutes, and a GCS score > 3) have a good prognosis of neurologically intact survival. A GCS score of 3 upon ED arrival and a PRISM score > 20 to 24 or a lack of neurologic improvement at 48 hours have a very poor prognosis. Colder water temperatures and hypothermia do not necessarily improve chances of survival. While lower pH and elevated potassium levels may suggest a poor outcome, there is insufficient data to adequately predict poor outcome with these measures.

Special Circumstances

Pediatric Drowning In Bathtubs, Buckets, And Spas

While the majority of drowning occurs in pools or natural bodies of water, special attention has been given to the risks of childhood drowning in buckets, bathtubs, and spas or whirlpools.

The latest CPSC report (2012) on home drowning documented 684 incidents of drowning or submersion events in children aged < 5 years involving bathtubs, buckets, bath seats, toilets, and landscape features from 2006 to 2010. An average of 87 incidences per year were fatal.⁹⁰ The majority of victims were aged < 2 years; 81% involved bathtubs, and 10% involved buckets.

Bucket Drowning

Bucket-related drowning has been reported in many drowning injury studies. Again looking at CPSC fatality data, 160 toddlers drowned in buckets over a 5-year period from 1984 to 1989.⁹¹ Most bucket drowning occurred inside the home as opposed to in the yard. Most children (88%) were aged 8 to 15 months. The 5-gallon industrial bucket, based on its height (14 inches) and stability, matches with the toddler's top-heavy center of gravity, and seems of particular risk. The authors of the study suggested anticipatory guidance regarding the dangers of these buckets.

Bathtub Drowning

Pearn described a series of 7 bathtub drownings, 2 of which were fatal.⁹² In each case, the infants (6 of the 7 were aged < 1 year) were left unattended in the bath with another sibling. In a study examining the role of bathtub seats and rings in infant deaths from drowning, data from the CPSC were analyzed.⁹³ Over a 13-year period from 1983 to 1994, 33 deaths were found to be directly attributable to dislodgment of the back seat or entrapment and submersion in the seat. The mean age of the infants was 8 months. Almost all cases included a lapse in parental supervision and the parents believing that the back seat would protect the infant from submersion.

Hot Tub And Spa Drowning

With the growing popularity of hot tubs and whirlpool spas starting in the 1970s, reports of childhood drowning in these locations increased. A 26-year survey of hot tub, spa, and whirlpool drowning in California documented the trend of increased childhood drowning.⁹⁴ Between 1960 and 1979, only 15 children drowned. By contrast, 59 cases of pediatric drowning were reported between the years of 1980 and 1985. Three cases were suction entrapment in males aged 9 to 10 years, and 90% of the drownings occurred in patients aged 10 months to approximately 3.5 years. In 2 cases, floating soft covers obscured the submerged child from rescuers.

Stagnant Or Contaminated Water

Particular attention should be paid to victims who have drowned in stagnant or contaminated water, water with a high amount of particulate matter, or warm water. Most authors recommend frequent sputum cultures and the use of antimicrobial agents directed at specific pathogens. In addition to causing pneumonia, some organisms (especially *Aeromonas hydrophilia*, *Chromobacterium violaceum*, *Burkholderia pseudomallei*, and *Francisella philomiragia*) are also frequently found in the blood cultures of drowning patients.²⁶ Invasive pulmonary and central nervous system (CNS) aspergillosis has been reported in a 10-month old severe drowning victim who was found in a stagnant pond.⁹⁵ *Pseudallescheria boydii*, a ubiquitous fungus, has been reported to cause late pneumonia in drowning victims as late as 4 to 6 months after the event. *P boydii* pneumonia and meningitis should be considered in any drowning victim who develops new respiratory or CNS symptoms even weeks or months after the drowning event.²⁶

Drowning And Nonaccidental Trauma

Many institutional or state reports of drowning injuries and deaths report a certain percentage for which investigation into the circumstances is inconclusive. Most drowning deaths (especially in children aged < 5 years) are due in part to a lapse in adult supervision. Where this lapse crosses over to frank neglect or even intentional abuse can be difficult to define. Conclusions from the following studies suggest a vigilance to examine all potentially suspicious histories and identify other injuries in drowning children that may suggest abuse, particularly in younger children.

Griest and Zumwalt described 6 cases of documented drowning deaths due to nonaccidental trauma.⁹⁶ All children were aged ≤ 3 years. Injuries noted on autopsy included contusions, lacerations around the mouth, chest wall bruising, petechiae of the conjunctiva, eyelids, face, ears, and extremities, and healing fractures on skeletal survey. Three of the cases had postmortem pathological pulmonary changes consistent with postimmersion syndrome, a secondary pulmonary injury characterized by intra-alveolar leukocytic infiltrates and edema. This finding is pathognomonic for homicide and can be distinguished from that of a drowning victim who survives with pulmonary edema in the hospital. Cerebral edema in 5 children was thought to indicate a delay between immersion and death. The authors summarized factors that raise concern for suspicious drowning for forensic pathologists, and recommended considering a skeletal survey and a thorough examination of drowning victims for bruising or other injuries that are inconsistent with the reported mechanism of drowning.

A review from Washington state over a time period from 1983 to 1991 examined 205 drownings,

with 2 pediatricians categorizing the cases that were suspicious of abuse.⁴⁵ Sixteen (7.8%) were classified as definitely inflicted or probably inflicted. Evaluation of 11 of the cases revealed physical findings consistent with abuse, another 3 had suspicious physical findings on examination, and 1 had radiologic findings. The majority (56%) of inflicted drownings occurred in the bathtub, and none of the victims were aged > 4 years old. Interestingly, of the children whose cases were classified as a “definitely or probably inflicted” drowning who survived to receive care in the ED (1 died), only 67% had social work documentation and 57% had a previous referral to Child Protective Services. This would suggest that inflicted drowning may sometimes be overlooked or missed by hospital staff. Inconsistent histories or delay in seeking care, as well as the presence of other injuries, should also raise some concerns to the possibility of nonaccidental trauma.

Controversies And Cutting Edge

Hypothermic Drowning Victims: Can There Be A Meaningful Recovery?

Since the report in 1962 of a 5-year-old boy who drowned in water at a temperature of -10°C and recovered neurologically intact after a 5-hour resuscitation,⁹⁷ multiple cases have documented remarkable recoveries of children who drown in cold water and were severely hypothermic.^{98,99} Perhaps the longest reported submersion was that of a 2-1/2-year-old rescued after 66 minutes. Apneic and pulseless, with an initial rectal temperature of 22.4°C and an initial pH of 7.25, the patient was placed on extracorporeal rewarming (ECR) 3 hours after arrival to the ED. She survived essentially neurologically intact and was discharged from the hospital 7 weeks later.¹⁰⁰ It is important to note that drowning in water < 10°C accounts for almost all of the reported cases of survival after prolonged submersion (> 15 minutes).

Encouraged by these case reports, there are many who advocate for the use of CPB or ECMO for the hypothermic drowning child who is in cardiorespiratory arrest. A question remains however – Is meaningful survival a reasonable expectation for all pediatric hypothermic drowning victims and could there be predictors that will guide us as to which of these children should undergo aggressive resuscitation? Evidence-based protocols for such resuscitations are needed.

Some authors who initially published case reports of survivals have later attempted to answer this question. A large study from Gottingen, Germany retrospectively reviewed the cases of 12 children (mean age of 3 years and 5 months) who drowned in water with an average temperature of 11.2°C and had a median submersion time of 25 minutes.¹⁰¹ All 12 children were in full cardiopulmonary arrest and had

a mean core temperature of 26.3°C upon arrival to the ED. All were started on CPB, and of these 12 patients, only 5 survived. Of the 5 children, only 2 survived neurologically intact. Variables (such as submersion time, body pH, potassium levels, core temperature, and rate of rewarming) were compared, and none of these factors were determined to be predictive of which children would survive neurologically intact.

Coskun et al reviewed 13 pediatric patients with a mean age of 3.2 years who were resuscitated.¹⁰² Average submersion time was 26 minutes, and average core temperature was 25.4°C. The patients arrived to the ED in asystole or ventricular fibrillation. Five patients (38.4%) survived to hospital discharge, and 2 patients (15.3%) had mild or no neurologic deficit.

A third single-center study reported a series of 9 children with hypothermic arrest (8 were drowning victims) who were placed on extracorporeal circulation (ECC).¹⁰³ The protocol for ECC excluded children with a core temperature > 30°C. Two children survived neurologically intact (22%). No differences in initial temperature, pH, or potassium levels were significant in distinguishing survivors versus nonsurvivors. They also reported the average hospital cost for survivors versus nonsurvivors of hypothermic arrest, \$65,224 and \$30,192, respectively. Identifying patients who are unlikely to survive can prevent unnecessary treatment and utilization of resources.

Extracorporeal Circulation Versus Extracorporeal Membrane Oxygenation

Both ECC and ECMO have been used to resuscitate hypothermic drowning patients. Some of the advantages of ECMO are that cannulation can be performed percutaneously, and ECMO also requires a lower level of anticoagulation. Also, prolonged support lasting several hours to days may be possible with ECMO. Reperfusion edema can be seen in hypothermic drowning patients and may require the longer support that ECMO can provide. One study

Time- And Cost-Effective Strategies

1. Do not order laboratory studies, such as electrolytes and complete blood count, for asymptomatic drowning victims.
2. Do not order cervical spine films for all drowning victims; only order them for patients with a history or physical findings suggestive of high-impact trauma.
3. Do not administer prophylactic antibiotics, as no reduction in pneumonia or mortality has been shown. Antibiotics should be reserved for strongly suspected or proven cases of bacterial infection.

Risk Management Pitfalls To Avoid For Pediatric Drowning Victims

- 1. "Those rib fractures in this 10-month-old's x-rays are most likely from a previous fall. He drowned in a bathtub, so we do not need to worry about those fractures right now."**

It is important to consider intentional injury (nonaccidental trauma or neglect) in patients presenting with incongruent histories, an obvious lapse in supervision, a delay in seeking care for submersion, and other injuries suggestive of nonaccidental trauma (such as bruises and old fractures).
- 2. "She looks fine now. We were able to wean her from oxygen, and she is otherwise well. She is stable to go home."**

Emergency clinicians should observe drowning victims for a 4- to 8-hour period. When discharging a patient home who is completely asymptomatic or who presented with mild symptoms and has since clinically improved, it is important to ensure close follow-up with a primary care physician. If follow-up cannot be established, admission for further observation should be considered.
- 3. "We can't register a temperature on this patient, but that's okay because we need to focus on regaining a heart rate first."**

It is important to check a core temperature on all drowning victims using a low-sensing thermometer if a conventional thermometer is unable to register a temperature. Hypothermia should be corrected during resuscitation, especially in cases in which the patient is in full cardiac arrest and multiple doses of drugs or defibrillation may be counterproductive.
- 4. "He fell through the ice, and it took 15 minutes for EMS to retrieve him, so I'm unsure he will survive."**

Many successful resuscitations have occurred in children drowned in icy water who initially have the appearance of being dead. Aggressive resuscitation and rewarming to a temperature to 34°C should commence, with consideration of institutional capabilities of CPB and ECMO for rewarming.
- 5. "The mother says he has frequent syncopal episodes, but I think that this drowning was just a case of his not being a strong swimmer."**

Consider underlying conditions (such as epilepsy, cardiac dysrhythmias, and hypoglycemia) when assessing drowning victims. Provide emergent care and ensure appropriate follow-up for any conditions found.
- 6. "I don't need to obtain cervical spine films for a drowning patient."**

Consider traumatic injuries sustained to the cervical spine in high-impact submersions (such as diving or a motor vehicle collision). If trauma to the head or neck is suspected based on history or physical examination, the cervical spine should be immobilized. However, routine immobilization and radiographs are not warranted based solely on a history of drowning. Cervical spine injuries are unlikely in low-impact submersions (such as swimming or bathing).
- 7. "They didn't have a fence around their pool, but they have probably learned after this experience."**

It's important to advocate for safety measures around pools and when participating in water sports. Clinicians should be aware of local/state pool and water safety laws. Consider obtaining social work intervention to review pool safety and other safety issues at home with the caregivers.
- 8. "This patient is at risk for ARDS. We should give him a methylprednisolone bolus."**

Avoid therapies for drowning that have not proven to be beneficial and are potentially harmful, such as corticosteroids, which can interfere with the healing process.
- 9. "Drowning is not an issue in my community. I've yet to see a case in my practice."**

Childhood drowning is an issue in every community throughout the world, as these incidents can occur in seemingly benign places, such as the bathtub or a bucket. The locations and dangers vary, and knowledge of the risk factors in your community will help you pre-plan resuscitation efforts, and advocate for targeted public education.
- 10. "This 10-year-old girl experienced a drowning event 3 weeks ago in the local pond. She stayed overnight in the hospital and was then discharged home. I don't understand why she's back with cough. It can't be pneumonia this far out from the event."**

Drownings that occur in stagnant or contaminated water are not only at higher risk for pneumonia in the first few days but also for late-onset pneumonia. One organism, *P boydii*, can cause pneumonia and meningitis and should be considered in any drowning victim who develops new respiratory or CNS symptoms even weeks or months after the drowning event.

has compared the use of ECC versus ECMO in pediatric and adult patients (drowning and other hypothermic injuries), and they found improved survival in the ECMO-supported patients.¹⁰⁴

In conclusion, ECC and ECMO are effective in the resuscitation of pediatric hypothermic (temperature < 30°C) drowning patients, but with a 22% neurologically intact survival rate, at best. Medical centers who receive hypothermic drowning victims should have a protocol in place for decision-making on the use of ECC and ECMO.

Prevention

Table 2 outlines major talking points in counseling families about water safety and children. These discussions with families may be especially valuable when a child has arrived to the ED for treatment of a non-life-threatening water-related event. Emergency clinicians should take time to counsel parents and caregivers on water safety and prevention methods. Parents and caregivers can also be referred to social work to discuss these issues in greater depth.

Case Conclusions

With continued fluid resuscitation for the 10-month old and a dopamine drip of 10 mcg/kg/min, the patient was stabilized and sent to the ICU. She eventually recovered from her respiratory insult, but remained in a persistent vegetative state when discharged from the hospital.

The 8-year-old boy was placed on 5 L facemask oxygenation to maintain a pulse oximetry of > 95%. A chest x-ray revealed diffuse pulmonary infiltrates consistent with pulmonary edema. He was admitted to the hospital, improved within 24 hours, and was subsequently discharged.

Two doses of epinephrine and 1 dose of sodium bicarbonate were given to the 2-year-old. Her initial pH was 6.6. After 40 minutes of continuous resuscitation, efforts were terminated.

Table 2. Interventions Identified To Reduce Drowning Rates In Developed Nations

- Four-sided pool fencing
- Swimming lessons for children aged ≥ 4 years
- Caregiver supervision/education
- CPR training for parents
- Swimming in lifeguard-monitored areas
- Personal floatation devices
- Spa /hot tub drain covers
- Awareness of bathtub and bucket drowning

Abbreviation: CPR, cardiopulmonary resuscitation.

References

Evidence-based medicine requires a critical appraisal of the literature based upon study methodology and number of subjects. Not all references are equally robust. The findings of a large, prospective, randomized, and blinded trial should carry more weight than a case report.

To help the reader judge the strength of each reference, pertinent information about the study will be included in bold type following the reference, where available.

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CME Questions



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1. **Mechanisms contributing to intrapulmonary shunting after a drowning event include:**
 - a. Bronchospasm
 - b. Inactivated, diluted, and/or diminished surfactant
 - c. Alveolar and interstitial edema
 - d. All of the above
2. **Common metabolic derangements in drowning include which of the following?**
 - a. Hypocarbia b. Hypoxemia
 - c. Alkalosis d. Hypernatremia
3. **Which of the following patient(s) who has sustained a drowning event is likely to need cervical spine immobilization?**
 - a. 6-month-old boy in the bathtub
 - b. 13-year-old girl swimming in the ocean
 - c. 17-year-old boy diving athlete
 - d. All of the above
4. **A 2-year-old girl has gone missing for a several minutes and is found face down in the backyard swimming pool. She is rescued by EMS personnel and is noted to be apneic and bradycardic. What is the initial management priority?**
 - a. Cervical spine immobilization
 - b. Abdominal thrusts to remove fluid from the lungs
 - c. Establishing an airway and bag-valve-mask ventilation with 100% oxygen
 - d. Chest compressions

5. Which of the following diagnostic studies would be the most appropriate to obtain for the 2-year-old patient in question 4 upon her arrival to the ED?
 - a. ABG, chest x-ray
 - b. ABG, CBC, electrolytes, chest x-ray
 - c. ABG, CBC, electrolytes, chest x-ray, cervical spine x-ray
 - d. ABG, chest x-ray, cervical spine x-ray

6. For the severely hypothermic drowning patient in cardiopulmonary arrest, which of the following is the initial priority?
 - a. Continued CPR and initiation of both passive and active rewarming
 - b. Treat acidosis aggressively with sodium bicarbonate
 - c. Consider either CPB or ECMO if available
 - d. Treat hyperkalemia

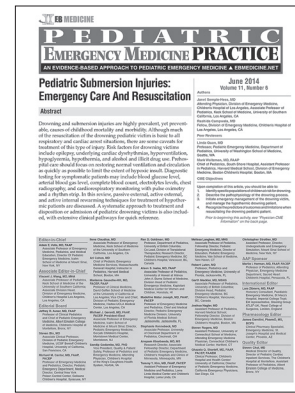
7. Which of the following are considered to be appropriate and effective active rewarming methods of hypothermic drowning patients?
 - a. Hot water bottles and warm blankets
 - b. Heat lamps
 - c. Removing all wet clothing
 - d. Warm intravenous fluids (at least 40°C) and bladder, peritoneal, or thoracic lavage

8. Which of the following treatments/management strategies should be employed in a ventilated drowning victim while awaiting transfer to the PICU?
 - a. Permissive hypercapnia
 - b. Glucocorticoid therapy
 - c. Neuromuscular blockade
 - d. Maintain mechanical ventilation for at least 24 hours even if gas exchange is adequate

9. Which of the following has been shown to be a significant indicator of poor neurological outcome in pediatric drowning?
 - a. GCS score of 8 on arrival to the ED
 - b. Submersion time > 25 minutes
 - c. Age > 10 years
 - d. CPR > 60 minutes

10. Counseling on pediatric water safety includes which of the following?
 - a. Alcohol should not be considered a risk factor in adolescent drowning.
 - b. Air-filled swimming aides (such as "water wings") may be used as a substitute for approved personal flotation devices.
 - c. Pool alarms and rigid pool covers may be used in place of 4-sided fencing.
 - d. Adults supervising children should be in the water or within arm's length of infants, toddlers, and weak swimmers.

Coming Soon In *Pediatric Emergency Medicine Practice*



Pediatric Inflammatory Bowel Disease: ED Implications And Management

Inflammatory bowel disease (IBD) includes both Crohn disease and ulcerative colitis. Twenty to thirty percent of IBD is diagnosed in childhood. Pediatric-onset IBD differs from adult IBD in disease type, location, progression, and gender preponderance. Extraintestinal manifestations, particularly growth delay, are the predominating presenting feature in childhood IBD.

IBD flares typically require intravenous steroids and inpatient admission. Acute emergencies include toxic megacolon, intestinal obstruction, and intestinal perforation. The use of steroids may also obscure diagnosis of an underlying abdominal emergency by masking signs and symptoms. The emergency clinician must be cognizant of such complications and diagnostic challenges.

Upon completion of this article, you should be able to:

1. Describe the differences between pediatric- and adult-onset inflammatory bowel disease as well as the differences between Crohn disease and ulcerative colitis.
2. Describe emergency department assessment and management of inflammatory bowel disease.
3. Identify and manage complications of inflammatory bowel disease.

In Volume 1 of the *Pediatric Emergency Medicine* Audio Series, Dr. Andrew Sloas reviews 4 critical pediatric topics and provides evidence-based treatment recommendations.

PRODUCT DETAILS:

- Evidence-based reviews on 4 critical pediatric patient presentations
- Convenient format: MP3 download of all 4 topics instantly after you order
- Speaker: Dr. Andrew Sloas
- Recording date: December 17, 2012
- Length: 81 minutes total
- CME: 2 *AMA PRA Category 1 Credits*[™]
- CME expiration date: January 1, 2016
- Price: \$59

TOPIC #1: Evaluation And Treatment Of Croup

This audio session will refresh your knowledge for the diagnosis and treatment of croup and introduce you to some new concepts, so you can avoid potential airway disasters in these patients. **Length:** 19 minutes

TOPIC #2: Pediatric Procedural Sedation

This audio review will expand your familiarity with multiple sedation medications, including new drugs, along with the more traditionally accepted therapies. You'll learn what medication choices are available and which techniques will increase your sedation safety profile. **Length:** 23 minutes

TOPIC #3: Acute Appendicitis In Childhood

This audio session examines the clinical manifestations of appendicitis that can vary from the nonspecific to the typically expected and covers special diagnostic dilemmas for pediatric patients. Detailed history-taking and appropriate laboratory testing are also discussed as a guide for evaluating the pediatric patient. **Length:** 22 minutes

TOPIC #4: Ovarian And Adnexal Torsion In Children

This audio review will give you an evidence-based approach to ovarian and adnexal torsion, so you'll know how to combine all tools available to you (history, physical examination, and ancillary testing) to correctly identify this condition. **Length:** 17 minutes

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Emergency Department Management Of Acute Hematogenous Osteomyelitis In Children	February 2014	4
Pediatric Herpes Simplex Virus Infections: An Evidence-Based Approach To Treatment	January 2014	4
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Physician CME Information

Date of Original Release: June 1, 2014. Date of most recent review: May 15, 2014. Termination date: June 1, 2017.

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Needs Assessment: The need for this educational activity was determined by a survey of medical staff, including the editorial board of this publication; review of morbidity and mortality data from the CDC, AHA, NCHS, and ACEP; and evaluation of prior activities for emergency physicians.

Target Audience: This enduring material is designed for emergency medicine physicians, physician assistants, nurse practitioners, and residents.

Goals: Upon completion of this activity, you should be able to: (1) demonstrate medical decision-making based on the strongest clinical evidence; (2) cost-effectively diagnose and treat the most critical ED presentations; and (3) describe the most common medicolegal pitfalls for each topic covered.

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