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Drowning (submersion injuries)

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INTRODUCTION

Drowning is essentially respiratory impairment from liquid submersion. Drowning accounts for at least 360,000 deaths annually worldwide, including approximately 5400 deaths annually in the United States [1,2]. Non-fatal drowning events occur much more frequently than deaths [3]. Drowning quickly causes respiratory and cardiac arrest from hypoxemia, while survivors can sustain pulmonary, neurologic, cardiovascular, and other injuries.

Drowning and its management are reviewed here. The management of specific complications of non-fatal drowning (eg, hypothermia and acute respiratory distress syndrome), complications of SCUBA diving, and the general management of trauma are discussed separately.

- (See "Accidental hypothermia in adults".)
- (See "Hypothermia in children: Management".)
- (See "Complications of SCUBA diving".)
- (See "Acute respiratory distress syndrome: Clinical features, diagnosis, and complications in adults".)
- (See "Initial management of trauma in adults".)
- (See "Trauma management: Approach to the unstable child".)

TERMINOLOGY

Consensus and society guidelines have standardized the definitions related to drowning to ensure a consistent approach to reporting and studying these incidents [4-8]. Terms such as "near-drowning," "secondary drowning," "wet drowning," and "dry drowning" should not be used. Accepted definitions include the following [5-7,9,10]:

- **Drowning** – "The process of experiencing respiratory impairment from submersion or immersion in liquid [8]."
- **Fatal drowning** – A drowning event with a fatal outcome.
- **Non-fatal drowning** – A drowning event in which the process of respiratory impairment is stopped before death, and the victim survives. The World Health Organization has proposed a framework to further classify non-fatal drowning based on the severity of respiratory impairment immediately after the drowning process has stopped [11]:
  - Mild impairment: Breathing, involuntary distressed coughing and fully alert
  - Moderate impairment: Difficulty breathing and/or disoriented but conscious
  - Severe impairment: Not breathing and/or unconscious
- **Rescue** – An intervention that prevents progression to drowning in an individual who is submerged but at no time develops respiratory symptoms or impairment.

EPIDEMIOLOGY

Drowning is a common cause of accidental death in the United States (US) and a prominent cause of childhood fatalities worldwide [12-18]. Low and middle-income countries have the highest rates of drowning, accounting for over 90 percent of cases worldwide. Statistics for non-fatal drowning are more difficult to obtain, but it is estimated that for every child that dies of drowning in the US, another eight receive care in an emergency department, and 40 percent of those require hospitalization [19].

In the US, drowning is a major cause of accidental death among persons under the age of 45 years, and a leading cause in children under five years of age in states where swimming pools or beaches are readily accessible (eg, California, Arizona, and Florida) [12,20-22]. The highest incidence of drowning occurs among males, African-Americans, children between the ages of one and five years (typically inadequately supervised in swimming pools, bathtubs, or around other liquid-filled containers), persons with low socioeconomic status, and residents of Southern states [13,18,23]. Approximately 7 percent of child drownings appear related to child abuse or neglect. Adult drownings tend to occur at rivers, lakes, and beaches [24]. Drowning is much more common during the summer months.

In Canada, a retrospective 10-year database review of 4288 fatal drowning victims found a median age of 44 years, and 80 percent were male [25]. Most drownings occurred in an urban region. The most common preceding activities were aquatic (ie, swimming) or boating, and the most common bodies of water involved were lakes, ponds, or flowing water. The victim was typically alone, and one-third had a preexisting condition (eg, cardiovascular disease, physical disability, seizure disorder). Victims who drowned in bathtubs (11 percent of total drownings) were more likely to have a seizure or neurocognitive disorder.

RISK FACTORS

The following factors increase the risk of drowning [1,12,22,24-34]:

- Inadequate adult supervision or being around bodies of water while alone
- Inability to swim or overestimation of swimming capabilities
- Risk-taking behavior
- Use of alcohol (more than 50 percent of adult drowning deaths involve alcohol, while a serum ethanol concentration ≥150 mg/dL is associated with a 37-fold increased risk of fatal drowning compared with sober controls) [35]
- Black American and Native American (including Alaska Natives) race/ethnicity (Black American teenagers drown in swimming pools much more commonly than White children of the same age) [36-38]
- Hypothermia, which can lead to rapid exhaustion or cardiac arrhythmias (see "Accidental hypothermia in adults")
- Concomitant trauma, stroke, or myocardial infarction
- Having a seizure disorder (which is associated with a nearly 20-fold increased risk of fatal drowning in children and adolescents)

- Developmental/behavioral disorders (in children) [39,40]
- Undetected primary cardiac arrhythmia (may be a more common cause of drowning than generally appreciated) [41]. Mutations in the cardiac ryanodine receptor (RyR)-2 gene, which is associated with familial polymorphic ventricular tachycardia in the absence of structural heart disease or QT prolongation, have been identified in some individuals with unexplained drowning [30]. In the Canadian retrospective study, having a history of ischemic heart disease increased risk of fatal drowning threefold [25]. (See "Congenital long QT syndrome: Epidemiology and clinical manifestations", section on 'Triggers of arrhythmia' and "Catecholaminergic polymorphic ventricular tachycardia".)
- Hyperventilation prior to a shallow dive (in order to prolong underwater duration). Swimmers commonly hyperventilate prior to submerging to reduce the arterial partial pressure of carbon dioxide ($PaCO_2$). As the individual swims, oxygen is consumed, thus the partial pressure of oxygen (PaO_2) can drop to 30 to 40 mmHg before the $PaCO_2$ rises sufficiently to trigger the urge to breathe. This can lead to cerebral hypoxia, seizures, and loss of consciousness, which can result in drowning. (See "Control of ventilation".)

PATHOPHYSIOLOGY AND CLINICAL FEATURES

General mechanism — Drowning typically begins with a period of panic, loss of the normal breathing pattern, breath-holding, air hunger, and struggling to stay above the water. Reflex inspiratory efforts eventually occur, leading to aspiration of water, coughing when water contacts the lower respiratory tract, and within minutes, hypoxemia, loss of consciousness, followed by apnea. Cardiac arrest occurs from hypoxemia and is preceded by bradycardia and pulseless electrical activity rather than a ventricular dysrhythmia [1,42-47]. Hypoxemia in turn affects every organ system, with the major component of morbidity and mortality from cerebral hypoxia [26].

The composition of the aspirated fluid is less important than the quantity. Aspiration of 1 to 3 mL/kg of liquid compromises the function of pulmonary surfactant and leads to respiratory compromise and hypoxemia. However, there are differences in fluid composition that can affect a patient's course and management. For example, the temperature of the water, tonicity, and the presence of contaminants may affect clinical sequelae as in the following [24,42,43]:

- Cold water submersion can cause ventricular dysrhythmia (discussed further below)

[48]

- Salt water drowning that results in cardiac arrest seemingly has worse outcomes, although multiple confounders exist [49]
- Water with high pathogen load (eg, sewage) increases risk for infection and sepsis

Organ specific effects, signs and symptoms

Pulmonary — Fluid aspiration results in varying degrees of lung injury [26]. Both salt water and fresh water wash out and destroy surfactant, disrupt the alveolar-capillary membrane, and increase its permeability. The fluid shifts often result in non-cardiogenic pulmonary edema and the acute respiratory distress syndrome (ARDS) [24,42]. Hypoxemia results from decreased lung compliance, ventilation-perfusion mismatching, and intrapulmonary shunting [50]. Both salt water and fresh water drowning cause lung injury, and the distinction is no longer considered important [51-55]. (See "Acute respiratory distress syndrome: Clinical features, diagnosis, and complications in adults".)

Pulmonary insufficiency can develop insidiously or rapidly. Increased respiratory rate and rhonchi, rales, or wheezing on pulmonary auscultation can precede more significant respiratory distress and radiologic findings. The chest radiograph or computed tomography (CT) at presentation can vary from normal to localized, perihilar, or diffuse pulmonary edema (image 1). Pulmonary symptoms can develop anytime in the initial eight hours after a drowning event, but are unlikely to develop beyond this initial period [56,57].

Neurologic — Approximately 20 percent of non-fatal drowning victims sustain neurologic damage from hypoxic-ischemic injury, typically from hypoxemia and hypoperfusion during cardiac arrest [58]. Neurologic injury limits functional recovery and results in long-term sequelae. Cerebral edema and intracranial pressure elevation, which are sometimes observed approximately 24 hours after injury, reflect the severity of the neurologic insult rather than its cause [59,60]. (See "Hypoxic-ischemic brain injury in adults: Evaluation and prognosis".)

Neurologic injury in a drowning victim can range from subtle signs to comatose lacking brainstem reflexes. Patients can present with myoclonic jerks or seizure activity. A comatose drowning victim can have non-convulsive status epilepticus that can only be identified with electroencephalography. Neurologic status can worsen if cerebral edema develops, but can also improve over time with substantial neurologic recovery despite initial poor neurologic examination. Prognostication based on the initial clinical neurologic examination can be inaccurate since it is often confounded by intoxicants, hypothermia, and metabolic derangements.

Cardiovascular — Cardiovascular effects after drowning stem from hypoxemia and hypothermia. A wide variety of dysrhythmias can be encountered including sinus tachycardia, sinus bradycardia, atrial fibrillation, pulseless electrical activity, and asystole [61]. Ventricular tachycardia and fibrillation are rare and likely occur from underlying structural or ischemic heart disease [49,62]. ST segment changes in the electrocardiogram (ECG) consistent with myocardial ischemia following non-fatal submersion may be due to takotsubo cardiomyopathy, coronary artery spasm, hypothermia, hypoxia, and less commonly, myocardial ischemia from occlusive coronary artery disease [63]. (See "Accidental hypothermia in adults", section on 'Electrocardiographic changes' and "Electrocardiogram in the diagnosis of myocardial ischemia and infarction".)

A patient with hypothermia can have significant hypovolemia and hypotension due to a "cold diuresis." During the early phase of vasoconstriction, blood is redirected to core organs, central volume receptors sense fluid overload, and antidiuretic hormone production decreases, resulting in increased urine production.

Cold water swimming (including diving) with attempted breath holding can precipitate fatal ventricular dysrhythmias, especially in patients with a congenital or acquired (ie, medication-induced) long QT syndrome [48,64]. This likely occurs from the "autonomic conflict" of dual activation of the sympathetic cold shock response and the parasympathetic diving response. Additionally, releasing a breath hold itself is an arrhythmogenic trigger. Dual activation of both arms of the autonomic nervous system can cause supraventricular and junctional dysrhythmias, but also predispose to ventricular dysrhythmias because myocytes are unable to regulate action potential duration in response to the abrupt change in heart rate. Essentially, the QT interval does not match the underlying heart rate and, in susceptible individuals, predisposes to the torsades de pointes type of polymorphic ventricular tachycardia. (See "Congenital long QT syndrome: Epidemiology and clinical manifestations", section on 'Triggers of arrhythmia'.)

Others

- A metabolic and/or respiratory acidosis is often observed [65].
- Significant electrolyte imbalances generally do not occur in non-fatal drowning survivors except those submerged in unusual media, such as the Dead Sea, where absorption of swallowed extremely concentrated seawater can produce life-threatening hypernatremia, hypermagnesemia, and hypercalcemia [66,67].

- In severe cases, multiorgan dysfunction syndrome can occur from a systemic inflammatory response [51,68,69].

- Renal failure can occur rarely after submersion, and is usually due to acute tubular necrosis resulting from hypoxemia, shock, hemoglobinuria, or myoglobinuria [70,71].

- Hemolysis and coagulopathy are rare potential complications of non-fatal drowning [72-76].

BYSTANDER INTERVENTIONS AND PREHOSPITAL CARE

Rescue and immediate resuscitation by bystanders and emergency medical personnel improves the outcome of drowning victims [17,77-80]. The need for cardiopulmonary resuscitation (CPR) is determined as soon as possible without compromising the safety of the rescuer or delaying the removal of the victim from the water. In a patient with cardiac arrest due to drowning, bystander CPR improves outcomes compared with no CPR; conventional CPR (ie, with expired-air resuscitation or "rescue breaths") is preferable to compression-only CPR [80].

- **Begin rescue breathing** – Bystanders should begin conventional CPR (starting with rescue breaths) as soon as possible. Ventilation is generally considered the most important initial treatment for victims in cardiac or respiratory arrest from submersion injury since the arrest is typically due to hypoxemia. Rescue breaths are particularly important as compared with the non-submersion adult cardiac arrest patient, where immediate uninterrupted chest compressions are emphasized. If the rescuer is unable or unwilling to perform rescue breaths, then they should be instructed to perform compression-only CPR. (See "Adult basic life support (BLS) for health care providers" and "Pediatric basic life support (BLS) for health care providers".)

  If the rescue team is highly trained with appropriate equipment (eg, ventilation adjuncts, flotation devices), then rescue breathing can begin in open water; however, this is technically challenging and should not delay ultimate rescue time [80]. For most circumstances, rescue breathing should begin as soon as the rescuer reaches shallow water or a stable surface. Do not delay rescue breathing to perform the Heimlich maneuver or other postural drainage techniques that attempt to remove water from the lungs, as they are of no proven value [17,81,82].

- **Palpate pulses** – A careful search for pulses should be performed before initiating chest compressions because sinus bradycardia and atrial fibrillation do not require immediate treatment. Pulses may be very weak and difficult to palpate if the drowning patient is hypothermic or has sinus bradycardia or atrial fibrillation. Do not delay administering rescue breaths to perform the pulse check. (See "Accidental hypothermia in adults", section on 'Arrhythmias not causing cardiac arrest'.)

- **Begin chest compressions** – Chest compressions should not be attempted in open water, but can be attempted on a boat if conditions allow and rescuers are trained and focus on performing high-quality compressions (which are technically more difficult on a boat).

- **Administer automated external defibrillator (AED) when appropriate** – If an AED is available and recommends defibrillation, delivery of a shock should be performed and is safe for a drowning victim [80]. However, before applying AED pads, the patient's wet clothes need to be removed and the chest, neck and upper abdomen dried (the care team should ideally be dry as well). (See "Automated external defibrillators".)

- **Provide supplemental oxygen** – High-flow oxygen-delivery systems should be used to ensure adequate oxygenation of spontaneously breathing patients. Administer 100 percent oxygen initially until oxygen saturation can be measured, then titrate inspired oxygen percentage to maintain the patient's saturation in a normal range to avoid complications of hyperoxia [80].

- **Manage the airway –** Patients with apnea, respiratory distress, or who are unable to protect their airway should be tracheally intubated via standard advanced airway principles if equipment is available. Otherwise, bag-mask ventilation (BVM) remains a reasonable approach during early care and prehospital transport. Particularly in areas with a high risk of respiratory infection from coronavirus disease 2019 (COVID-19) or comparable pathogens, BVM devices should be equipped with a high-efficiency particulate air (HEPA) filter. A review of 2388 drowning victims with cardiac arrest found that use of supraglottic airway devices (compared with tracheal intubation or BVM) decreased odds of overall survival, but there was no difference in survival with good neurologic outcome between any of these airway techniques [83]. (See "Overview of advanced airway management in adults for emergency medicine and critical care" and "Emergency endotracheal intubation in children".)

- **Keep the victim warm** – Attempts at rewarming hypothermic patients with a core temperature <33°C should be initiated, either by passive or active means as available.

(See "Accidental hypothermia in adults".)

- **Cervical spine immobilization not routinely needed** – Cervical spinal cord injury is uncommon in non-fatal drowning victims, unless there are clinical signs of injury or a concerning mechanism (eg, dive into shallow water). Routine cervical spine immobilization is not recommended since it can interfere with essential airway management [10,82]. A cohort study of 2244 submersion victims reported that 11 (0.5 percent) sustained cervical spine injuries, and all had obvious signs of injury and a mechanism (eg, diving, motor vehicle crash) consistent with spinal trauma [84]. Altered mental status (eg, intoxication) can confound evaluation of spinal injuries in non-fatal drowning patients. (See "Evaluation and initial management of cervical spinal column injuries in adults", section on 'Spinal immobilization'.)

PATIENT IN CARDIAC ARREST

Continue resuscitation until patient warm — In a hypothermic patient with cardiac arrest, we suggest continuing resuscitative efforts until the patient's core temperature reaches 32 to 35°C (93 to 95°F) and asystole has been present for at least 20 minutes [85,86]. Survivors are likely to have a poor neurologic outcome if the return of spontaneous circulation (ROSC) does not occur within 30 minutes of the initiation of advanced life support, except when hypothermia occurs prior to submersion [87]. Prolonged resuscitative efforts can be effective, even if continued for several hours. Patients have had complete recovery despite prolonged resuscitation (after submersion for as long as 90 minutes), possibly because of the neuroprotective effects of hypothermia [88-90]. Prolonged resuscitations appear more likely to be effective when drowning occurs in cold water (≤6°C) or circumstances suggest that hypothermia preceded asphyxia, although data are limited, and the relative benefits of cold water have been questioned [91]. (See "Accidental hypothermia in adults", section on 'Cardiopulmonary resuscitation' and 'Outcome' below.)

Extracorporeal cardiopulmonary resuscitation — In a setting where conventional CPR is failing and extracorporeal membrane oxygenation (ECMO) is available, extracorporeal cardiopulmonary resuscitation (ECPR; venoarterial ECMO in conjunction with CPR) may be a salvage option and considered on a case-by-case basis [89,92-100]. In patients with mixed hypoxic and hypothermic cardiac arrest who undergo ECPR, neurologically intact survival is reported between 5 and 22 percent, although studies include a small number of patients and are retrospective. Patients with an initial core temperature <26°C (79°F) and a normal serum potassium concentration tended to have better outcomes.

Post-arrest management — We believe it is reasonable to perform targeted-temperature management (TTM) for all drowning patients not following commands after ROSC. However, the optimal goal temperature in the postresuscitation period following drowning remains unclear because high-quality evidence is lacking. A reasonable approach is TTM maintaining a core temperature between 33 and 36°C for at least 24 hours, similar to management of post-cardiac arrest from other causes. Many patients may already be at this temperature from environmental exposure and the mixing of cooler peripheral blood with core blood. The initiation and on-going management of TTM are discussed separately. (See "Initial assessment and management of the adult post-cardiac arrest patient", section on 'Temperature management'.)

Case series have reported no clear improvement in outcome following the use of TTM [101,102], and the treatment has been associated with an increased incidence of sepsis, probably secondary to cold-induced immunosuppression [58,102,103]. However, other case reports describe improved outcomes following TTM [104,105], and several guidelines and expert opinions support TTM as a possible intervention [10,89,106,107]. Regardless, hyperthermia should be avoided, as it increases cerebral metabolic demands and lowers the seizure threshold.

Management of the patient immediately after ROSC is discussed further in detail elsewhere. (See "Initial assessment and management of the adult post-cardiac arrest patient" and "Pediatric advanced life support (PALS)", section on 'Early post-cardiac arrest management'.)

PATIENT WITH PERFUSING RHYTHM

Overview and general principles — Care of the drowning victim who is breathing spontaneously, who is in respiratory arrest, or who has return of spontaneous circulation (ROSC) after cardiac arrest focuses on general supportive measures, addressing organ-specific injuries, performing imaging and laboratory studies, and determining disposition.

- **Address airway, breathing, and circulation** – If a patient in respiratory arrest does not start breathing spontaneously with bag-mask ventilation, they should be tracheally intubated and started on mechanical ventilation. Supportive measures specific to the drowning victim are discussed further below. (See 'Hypoxemia' below and 'Hypotension' below.)

- **Role of cervical spine immobilization** – Injury of the cervical spine **is not** common in patients with submersion injuries, but precautions should be taken if there is a concerning history (eg, dive into shallow water), evidence of head/neck trauma, or signs of neurologic deficit.

- **Monitoring** – Monitoring of the symptomatic patient should include continuous oxygen saturation and cardiac telemetry. Waveform end-tidal CO_2 should be used for patients requiring ventilatory support. Continuous core temperature monitoring with a low-reading thermometer should be instituted in hypothermic patients. (See "Pulse oximetry" and "Carbon dioxide monitoring (capnography)" and "Accidental hypothermia in adults", section on 'Temperature measurement'.)

- **Address bronchospasm** – Bronchospasm often occurs in non-fatal drowning victims and is treated similarly to acute asthma with inhaled beta-adrenergic agonists. (See "Acute exacerbations of asthma in adults: Home and office management" and "Acute asthma exacerbations in children younger than 12 years: Inpatient management".)

- **Role of prophylactic antibiotics** – Administer broad-spectrum antibiotics only if drowning occurred in heavily contaminated water (eg, sewage). Prophylactic antibiotics are not needed if drowning occurred in a pool, river, lake, or ocean [51,108].

- **Ineffective therapies** – There is no role for glucocorticoids, exogenous surfactant, or barbiturates. (See 'Ineffective or investigational therapies' below.)

Initial testing — The following evaluation should be performed in all patients who are symptomatic when they present for care:

- Measure core temperature with a low-reading thermometer (tympanic temperature measurement can be unreliable in drowning victims due to liquid in the external auditory canal)

- Reliable pulse oximetry saturation or arterial blood gas

- Chest radiograph (CXR)

- Electrocardiogram (ECG). Obtain troponin in patients with ECG changes or signs of cardiovascular toxicity (eg, hypotension, dysrhythmia)

- Serum electrolytes and creatinine, liver function tests, blood counts, and prothrombin time

- Serum ethanol concentration (except in children), given the association between alcohol use and drowning

- Evaluation for injuries with indicated imaging (see "Initial management of trauma in adults" and "Approach to the initially stable child with blunt or penetrating injury" and "Trauma management: Approach to the unstable child")

Patients with persistently altered mental status should have the following:

- Bedside glucose measurement upon arrival
- Brain CT

Management

Hypoxemia

Support oxygenation and ventilation — A drowning victim with hypoxemia most likely has developed lung injury or pulmonary edema and will need support of oxygenation and ventilation. Indications for tracheal intubation include the following:

- Signs of neurologic deterioration or inability to protect the airway
- Inability to maintain a PaO_2 above 60 mmHg or oxygen saturation (SpO_2) above 90 percent despite use of a high-flow oxygen-delivery system or non-invasive ventilation (NIV)
- Evidence of ventilatory failure with worsening respiratory acidosis (rising PaCO2 or decreasing pH) despite optimal non-invasive support

If tracheal intubation is performed, an orogastric tube should be placed to relieve gastric distension, which occurs from passive passage of fluid and is common in drowning patients.

In a hypoxemic patient who does not require immediate tracheal intubation, supplemental oxygen should be provided (eg, via nasal cannula or face mask) to maintain normal SpO_2. If hypoxemia persists or there are signs of ventilatory failure, then positive pressure NIV via continuous positive airway pressure (CPAP) or bilevel positive airway pressure (BPAP) can improve oxygenation and decrease ventilation-perfusion mismatch [80,109]. In drowning patients with moderate to severe lung injury, NIV has been used successfully to manage hypoxemia, and many patients can wean off NIV in one to two days. Positive airway pressure increases intrathoracic pressure, and patients must be carefully monitored for hypotension. NIV can induce vomiting and further aspiration by contributing to gastric distension, which is a particular concern in drowning victims. (See "Noninvasive ventilation in adults with acute respiratory failure: Benefits and contraindications".)

Positive pressure ventilation, either non-invasive or invasive, improves hypoxemia in drowning victims by maximizing and maintaining alveolar recruitment and thereby reducing ventilation-perfusion mismatch. High positive end-expiratory pressures (PEEP) may also improve gas exchange by promoting the resorption of fluid from the alveoli into the vasculature.

Ventilatory strategies — Mechanical ventilatory strategies are similar to those employed in other types of acute lung injury, and include the following goals (see "Ventilator management strategies for adults with acute respiratory distress syndrome"):

- Increase PEEP if needed to achieve adequate oxygenation.
- Use lung protective strategies, which would include starting with a low tidal volume (6 mL/kg ideal body weight) (table 1).
- In patients with concern for hypoxic-ischemic brain injury, permissive hypercapnia should be avoided.

Role of bronchoscopy — There is no role for routine bronchoscopy in a drowning victim unless there is clear evidence of aspiration of foreign material. (See "Flexible bronchoscopy in adults: Indications and contraindications", section on 'Therapeutic indications'.)

Extracorporeal membrane oxygenation for refractory hypoxemia — In a patient with severe acute respiratory distress syndrome (ARDS) who is persistently hypoxemic despite optimal invasive ventilation, we suggest initiating venovenous extracorporeal membrane oxygenation (ECMO) if available. ECMO is most likely to benefit a patient who is not severely acidemic, has not developed organ failure (especially kidney failure), and has not suffered a prolonged cardiac arrest with consequent concern for severe neurologic injury. Additionally, ECMO can also provide active rewarming in the persistently hypothermic patient. (See "Extracorporeal membrane oxygenation (ECMO) in adults".)

Observational studies report good neurologic outcomes in patients who did not suffer cardiac arrest, and who receive ECMO for respiratory rather than circulatory support [104,110-113]. In a multicenter registry spanning 30 years (247 drowning patients), 71 percent who received extracorporeal life support (ECLS) and did not suffer a cardiac arrest survived to hospital discharge (compared with 57 and 23 percent who either had a cardiac arrest before ECLS or had ECLS during cardiac arrest, respectively) [111]. Outcomes were similar between adult and pediatric patients. Mortality was higher in patients who presented with severe acidemia (pH <7.0), developed renal failure (Cr >1.5 mg/dL), and required venoarterial instead of venovenous ECMO.

Natural history of lung injury — The duration of submersion and extent of hypoxic injury predicts the ultimate clinical course. Most patients without respiratory or cardiac arrest will have a good outcome and fully recover. Acute lung injury and pulmonary edema are usually reversible. Some patients with mild lung injury will require supplemental oxygen for 6 to 48 hours, then improve and be discharged home [65]. Most other patients will need a period of non-invasive ventilation (NIV) or tracheal intubation for invasive ventilatory support. Patients with lung injury will probably require at least two days of support since that is typically the time required to regenerate surfactant [109].

Pneumonia — Antibiotics should be reserved for cases of clinical pulmonary infection (eg, fever, leukocytosis, new radiographic infiltrate that develops two to three days after drowning) or if the victim was submerged in grossly contaminated water. If pneumonia follows non-fatal drowning, suspect infection with water-borne pathogens, such as Aeromonas, Pseudomonas, and Proteus [114]. (See "Aeromonas infections", section on 'Therapy' and "Pseudomonas aeruginosa pneumonia", section on 'Management'.)

Persistent altered mental status — A patient with a persistently altered mental status may have suffered hypoxic-ischemic neurologic injury and/or have non-convulsive status epilepticus. The goal of hospital management is to prevent secondary neurologic injury due to ongoing ischemia, cerebral edema, hypoxemia, fluid and electrolyte imbalances, acidosis, and seizure activity. In a drowning patient who remains comatose, aspects of treatment include the following [10,58,89,101-106] (see "Hypoxic-ischemic brain injury in adults: Evaluation and prognosis"):

- Avoid hypoxemia, hypercarbia, hypotension, pain, urinary retention, or agitation, as these can raise intracranial pressure and/or worsen cerebral oxygenation.

- The head of the bed should be elevated to 30 degrees if potential spinal cord injuries have been excluded, and the patient is not hypotensive.

- For patients in imminent danger of cerebral herniation (eg, unilateral dilated pupil), standard brain resuscitation techniques (eg, head of bed elevation, hyperventilation, administration of hypertonic saline bolus or intravenous 20% mannitol) should be instituted as soon as possible to temporarily reduce intracranial pressure. (See "Evaluation and management of elevated intracranial pressure in adults", section on 'Urgent situations'.)

Prolonged hyperventilation should be avoided because it causes cerebral vasoconstriction, decreases cerebral blood flow, and worsens cerebral ischemia. Therefore, hyperventilation, as well as other brain resuscitation techniques, are merely a bridge to more definitive interventions such as ventriculostomy or decompressive craniectomy. (See "Evaluation and management of elevated intracranial pressure in adults", section on 'Decompressive craniectomy'.)

- A comatose drowning victim (especially if having myoclonic activity) should have an electroencephalogram (EEG) to exclude status epilepticus. Even if there is no myoclonic activity, an EEG should be obtained to exclude non-convulsive status epilepticus if mental status remains poor. (See "Hypoxic-ischemic brain injury in adults: Evaluation and prognosis", section on 'Electroencephalography' and "Electroencephalography (EEG) in the diagnosis of seizures and epilepsy".)

- Seizure activity, which increases cerebral oxygen consumption and blood flow, should be aggressively controlled. Non-sedating anticonvulsants (eg, phenytoin) are preferred because they do not complicate neurologic assessment. (See "Hypoxic-ischemic brain injury in adults: Evaluation and prognosis", section on 'Seizures'.)

- Adequate sedation should be provided to reduce patient-ventilator dyssynchrony, which can increase intracranial pressure. If possible, neuromuscular blocking agents should be avoided because they can interfere with neurologic assessment. (See "Sedative-analgesic medications in critically ill adults: Properties, dose regimens, and adverse effects" and "Neuromuscular blocking agents in critically ill patients: Use, agent selection, administration, and adverse effects".)

- Unless performing targeted-temperature management (TTM), maintain euthermia. Avoid hyperthermia since it increases cerebral metabolic demand. (See "Evaluation and management of elevated intracranial pressure in adults", section on 'Fever' and "Elevated intracranial pressure (ICP) in children: Management", section on 'Temperature control'.)

- Maintain euglycemia as both hypoglycemia and hyperglycemia may be harmful to the brain. (See "Glycemic control in critically ill adult and pediatric patients".)

- Diuretics can be used to avoid hypervolemia and to treat elevated intracranial pressure, but equal care should be taken to avoid volume depletion, which can lower cardiac output and cerebral perfusion. (See "Evaluation and management of elevated intracranial pressure in adults", section on 'Osmotic therapy and diuresis' and "Elevated intracranial pressure (ICP) in children: Management", section on 'Hyperosmolar therapy'.)

- Delayed cerebral edema may develop 24 hours after the initial hypoxic-ischemic injury and carries a poor prognosis. (See "Hypoxic-ischemic brain injury in adults: Evaluation and prognosis" and "Evaluation and management of elevated intracranial pressure in adults" and "Elevated intracranial pressure (ICP) in children: Management".)

Hypotension — In a patient with hypotension, administer intravenous crystalloid to counter the effects of immersion diuresis and correct other potentially contributing etiologies such as hypoxemia, acidosis, hypothermia, spinal shock, and effects of ingestions [54,115,116]. If ultrasound equipment and proficiency is available, an extended Focused Assessment with Sonography for Trauma (E-FAST) examination can evaluate for occult trauma and concurrently assess fluid status by imaging inferior vena cava diameter changes with the respiratory cycle. (See "Emergency ultrasound in adults with abdominal and thoracic trauma", section on 'Focused Assessment with Sonography for Trauma' and "Novel tools for hemodynamic monitoring in critically ill patients with shock", section on 'Vena cava assessment'.)

If hypotension is refractory to these measures, initiate a vasopressor (eg, norepinephrine) infusion. A patient with persistent hypotension may have developed a cardiomyopathy, decreased cardiac output, or high pulmonary vascular resistance [63,117-119]. An echocardiogram and/or pulmonary artery catheterization can be helpful to determine etiology of hypotension and provide data that can assist in optimal fluid replacement and inotropic support. Any unstable cardiac rhythm that might be contributing to the hypotension should be treated using advanced cardiac life support/pediatric advanced life support (ACLS/PALS) principles. (See "Use of vasopressors and inotropes" and "Pulmonary artery catheterization: Interpretation of hemodynamic values and waveforms in adults" and "Advanced cardiac life support (ACLS) in adults" and "Pediatric advanced life support (PALS)".)

Hypothermia — In the awake hypothermic patient, remove wet clothing and initiate passive external rewarming (eg, application of warm blankets, plumbed garments, heating pads, radiant heat, forced warm air). In a patient with ROSC or with signs of severe neurologic injury, TTM (goal core temperature between 33 and 36°C) and not normothermia may be the goal. Patients who remain unresponsive and hypothermic (below TTM goal temperature) may require active internal core rewarming (eg, warmed humidified oxygen via tracheal tube, heated irrigation of peritoneal and pleural cavities). In addition, endovascular and extracorporeal rewarming options are available in some centers. (See 'Post-arrest management' above and "Accidental hypothermia in adults".)

DISPOSITION

Asymptomatic individual — An asymptomatic individual who was submerged but at no time develops respiratory symptoms or impairment (ie, at no time has a cough), has recollection of all of the events, and has normal oxygen saturation and vital signs, can be discharged without testing or observation as long as a responsible adult can provide home monitoring. They should be instructed to return to the emergency department (ED) immediately if they develop any symptoms.

Symptomatic patient with normal oxygen saturation — A patient who has developed any respiratory symptoms (eg, cough) needs a minimum observation of eight hours. A drowning victim with normal oxygen saturation and initial chest radiograph (CXR) can be discharged if all of the following criteria are met at the end of the observation [80]:

- Normal mentation
- No new or worsening respiratory symptoms
    - If the patient has a cough, it should be improving prior to discharge
    - Any subjective dyspnea should resolve prior to discharge
- Normal age-adjusted vital signs
- Supplemental oxygen requirement does not develop
- Normal pulmonary auscultation

A review of 75 pediatric patients found that all who ultimately developed symptoms did so within seven hours of immersion [120]. Similar analyses in adults and children support these recommendations [56,57,121-123].

Discharged patient should be provided clear instructions to return to the ED immediately for any worsening respiratory symptoms and be accompanied by a responsible adult.

Hypoxic and other severely ill patients — Most symptomatic drowning victims will need hospitalization because of the severity of illness, concern for clinical deterioration, expected duration of requiring respiratory support, or treatment of organ-specific complications. A patient who had witnessed apnea, cardiac dysrhythmia, hypoxemia, or abnormal CXR should be admitted. Most patients who were unconscious will need admission, unless they were unconscious briefly and presented to the ED awake and meet all the above criteria for discharge. Ultimately, the duration of submersion and extent of hypoxic injury predicts the ultimate clinical course and anticipated length of hospitalization.

INEFFECTIVE OR INVESTIGATIONAL THERAPIES

- **Glucocorticoids** – There is no good evidence to support the routine use of glucocorticoids for acute lung injury in drowning victims [43,51,72].
- **Intracranial pressure monitoring** – Aggressive measures to reduce elevated intracranial pressure, as well as intracranial pressure monitoring, have not been documented to improve outcomes and are rarely undertaken [60].
- **Surfactant** – Researchers have investigated the use of exogenous surfactant to treat submersion injury with respiratory failure, with the rationale of replacing washed out surfactant [124,125]. Although there are case reports of surfactant treatment with good outcomes [126], no trials have been performed in non-fatal drowning victims, and there is no high-quality evidence that pulmonary function improves with surfactant therapy. (See "Acute respiratory distress syndrome: Investigational or ineffective therapies in adults", section on 'Ineffective or harmful therapies'.)
- **Barbiturates** – The use of barbiturates (combined with controlled hypothermia) in unconscious non-fatal drowning victims was reported to decrease mortality and neurologic morbidity in children [127]. However, subsequent studies failed to show any benefit from this therapy [46]. As an example, one study of 31 comatose, drowned children did not show a difference in outcomes between those treated with mild hypothermia alone, and those treated with mild hypothermia plus pentobarbital [128].

OUTCOME

Duration of submersion is the most critical factor in determining outcome; the rate of death or severe neurologic injury is just 10 percent when submerged less than five minutes. Evidence pertaining to survival following a submersion injury is limited to a large case-control study and other case series. Reported survival rates for drowning victims vary widely [91,129,130], but in patients who survive to hospital discharge neurologically intact, long-term survival appears to be similar to the general population [131,132]. The following factors at presentation have been associated with a poor prognosis [3,89,91,133-142]:

- Duration of submersion >5 minutes (most critical factor)
- Time to effective basic life support >10 minutes
- Resuscitation duration >25 minutes
- Age >14 years
- Glasgow coma scale <5 (ie, comatose)
- Persistent apnea and requirement of cardiopulmonary resuscitation in the emergency department
- Arterial blood pH <7.1 upon presentation

High-quality evidence or prognostic scales to identify early predictors of poor neurologic outcomes that can assist in the decision to discontinue medical care do not exist, and substantial neurologic recovery has been reported following prolonged submersion and anoxia [46,143-145]. However, the absence of spontaneous, purposeful movements 24 hours after drowning is an ominous sign; one study of 44 children found that all such patients died or suffered severe neurologic sequelae [146].

Cold water submersion may benefit drowning victims by decreasing metabolic demands and activating the diving reflex, a primitive reflex of bradycardia and breath-holding that shunts blood to the vital organs. However, a case-control study of 1094 open water drownings recorded between 1975 and 1996, many of which occurred in colder water, did not find an association between water temperature and survival with a "good outcome" (defined as no, mild, or moderate neurologic sequelae) [91]. The study did find associations between good outcomes and the duration of submersion (88 percent were submerged less than six minutes) as well as with patient age (children younger than five years did best). Suspected drug or alcohol abuse preceding the drowning was associated with a worse outcome (defined as death or survival with severe neurologic sequelae). Resuscitation standards have changed over the intervening decades since these data were collected, thus it is difficult to draw firm conclusions.

PREVENTION

Drowning is preventable in most cases [1,12]. As an example, secure (four-sided) fencing and gating of swimming pools can exclude virtually all children under the age of four and potentially decrease swimming pool drowning by 80 percent [12,147]. The importance of adequate adult supervision, swimming with a partner, appropriate use of personal flotation devices, and avoidance of alcohol and illicit drugs while swimming or boating should be stressed by physicians and public health authorities [12,46,147,148]. Parents must also be warned that toddlers can drown in shallow areas, including bathtubs, toilets, and buckets of water, if not adequately supervised, which includes strict attention and arm's length presence [147,149,150]. The American Academy of Pediatrics (AAP) and Centers for Disease Control and Prevention (CDC) resources related to drowning are available on their respective websites.

SOCIETY GUIDELINE LINKS

Links to society and government-sponsored guidelines from selected countries and regions around the world are provided separately. (See "Society guideline links: Management of environmental emergencies" and "Society guideline links: Hypothermia".)

SUMMARY AND RECOMMENDATIONS

- **Terminology** – Drowning is the process of experiencing respiratory impairment from submersion or immersion in liquid. Non-fatal drowning is when the process is interrupted, but the patient develops some form of respiratory impairment (eg, coughing, trouble breathing). A rescue is interruption of the drowning process without any respiratory impairment. (See 'Terminology' above.)

- **Risk factors** – These include inadequate supervision, being around bodies of water alone, inability to swim or overestimation of swimming capabilities, risk-taking behavior, use of alcohol, hypothermia, having a seizure disorder or cardiovascular disease, and developmental disorder in children. (See 'Risk factors' above.)

- **Pathophysiology** – Drowning causes hypoxemia, loss of consciousness, apnea, and ultimately cardiac arrest. Fluid aspiration results in lung injury and acute respiratory distress syndrome. Cerebral hypoxic-ischemic injury is a major factor in morbidity and mortality. Hypothermia is common and can be neuroprotective if it develops before the submersion. Cold water swimming (including diving) with attempted breath holding can precipitate ventricular arrhythmias in patients with a congenital or acquired long QT syndrome. (See 'Pathophysiology and clinical features' above.)

- **Cardiac arrest** – Resuscitation follows standard protocol, except compression-only CPR is not preferred since ventilation is generally considered the most important initial treatment. We suggest continuing resuscitative efforts until the patient's core temperature reaches 32 to 35°C (93 to 95°F) and asystole has been present for at least 20 minutes (**Grade 2C**). Prolonged resuscitative efforts lasting hours can be effective when drowning occurs in cold water (≤6°C), or circumstances suggest that hypothermia preceded asphyxia (even after submersion for as long as 90 minutes). (See 'Patient in cardiac arrest' above.)

  - **Extracorporeal cardiopulmonary resuscitation** – In patients where conventional CPR is failing and extracorporeal membrane oxygenation (ECMO) is available, extracorporeal cardiopulmonary resuscitation (ECPR; venoarterial ECMO in conjunction with CPR) may be a salvage option and considered on a case-by-case basis. An initial core temperature <26°C (79°F) and a normal serum potassium concentration portend better outcomes. (See 'Extracorporeal cardiopulmonary resuscitation' above.)

  - **Targeted-temperature management (TTM)** – In a drowning patient with return of spontaneous circulation after cardiac arrest, we maintain a core temperature between 33 and 36°C for at least 24 hours. (See 'Post-arrest management' above and "Initial assessment and management of the adult post-cardiac arrest patient", section on 'Initiation, target temperature, and duration of treatment'.)

- **Support oxygenation and ventilation** – In the symptomatic spontaneously breathing patient with a perfusing rhythm, perform tracheal intubation for signs of neurologic deterioration, inability to protect the airway, inability to maintain oxygen saturation (SpO_2) above 90 percent despite use of a high-flow oxygen-delivery system or non-invasive ventilation, or evidence of ventilatory failure. (See 'Support oxygenation and ventilation' above.)

  In a patient who does not require immediate tracheal intubation, supplemental oxygen should be provided (eg, via nasal cannula or face mask) to maintain normal SpO_2. Positive pressure non-invasive ventilation (NIV) can improve oxygenation and be a bridge to tracheal intubation or be weaned off in one or two days in some patients.

  - **Strategies to manage acute lung injury** – Ventilatory strategies are similar to those employed in other types of acute lung injury, including increasing positive end-expiratory pressure (PEEP) to achieve adequate oxygenation and a low tidal-volume (6 mL/kg ideal body weight) lung protective approach (table 1). (See 'Ventilatory strategies' above and "Ventilator management strategies for adults with acute respiratory distress syndrome", section on 'Efficacy and harm'.)

  - **Refractory hypoxemia** – In a drowning patient with persistent hypoxemia despite optimal ventilator management who did not suffer a prolonged cardiac arrest, we initiate venovenous ECMO when available. Good rates of hospital survival have been reported in patients who present without severe acidemia (pH >7.0), do not develop renal failure (Cr <1.5 mg/dL), and do not require circulatory support. (See 'Extracorporeal membrane oxygenation for refractory hypoxemia' above.)

- **Address injuries and hypothermia** – Remove wet clothing and initiate rewarming in hypothermic patients. Measure core temperature with a low-reading thermometer and **not** a tympanic thermometer. Evaluate for and address potential injuries. Cervical spinal cord injury is uncommon in non-fatal drowning victims, **unless** there are clinical signs of injury or a concerning mechanism (eg, dive into shallow water). (See 'Overview and general principles' above and 'Hypothermia' above.)

- **Studies to obtain in symptomatic patients** (see 'Initial testing' above):

  - Bedside glucose measurement upon arrival in any patient with altered mental status
  - Chest radiograph (CXR)
  - Electrocardiogram (ECG)
  - Serum electrolytes and creatinine, liver function tests, blood counts, and prothrombin time
  - Serum ethanol concentration in adolescent and adult patients
  - Troponin if ECG changes or signs of cardiovascular toxicity (eg, hypotension, dysrhythmia)
  - Reliable pulse oximetry saturation or arterial blood gas
  - Brain CT if persistent altered mental status
  - Focused imaging based on concern for injury

- **Altered mental status** – A patient with a persistently altered mental status may have suffered hypoxic-ischemic neurologic injury and/or have non-convulsive status epilepticus. The goal of management is to prevent secondary neurologic injury due to ongoing ischemia, cerebral edema, hypoxemia, fluid and electrolyte imbalances, acidosis, and seizure activity. A comatose drowning victim (especially if having myoclonic activity) should have an electroencephalogram to exclude non-convulsive status epilepticus. (See 'Persistent altered mental status' above.)

  For a patient in imminent danger of cerebral herniation (eg, unilateral dilated pupil), standard brain resuscitation techniques (eg, head of bed elevation, hyperventilation, administration of hypertonic saline bolus or intravenous 20% mannitol) should be instituted as soon as possible to temporarily reduce intracranial pressure as a bridge to other more definitive interventions. (See "Evaluation and management of elevated intracranial pressure in adults", section on 'Urgent situations'.)

- **Hypotension** – A patient with persistent hypotension may have hypoxic cardiomyopathy, decreased cardiac output, or high pulmonary vascular resistance. An echocardiogram and/or pulmonary artery catheterization can be helpful to determine etiology of hypotension and provide data that can assist in optimal fluid replacement and inotropic support. (See 'Hypotension' above.)

- **Disposition** – Most symptomatic drowning victims will need hospitalization because of the severity of illness, concern for clinical deterioration, need for supportive care, or treatment of organ-specific complications. (See 'Hypoxic and other severely ill patients' above.)

  A drowning victim with normal oxygen saturation and initial CXR can be discharged after an eight-hour observation if they have normal mentation, age-adjusted vital signs, pulmonary auscultation examination, have not developed new or worsening respiratory symptoms, and do not have a supplemental oxygen requirement. (See 'Symptomatic patient with normal oxygen saturation' above.)

- **Outcomes** – Duration of submersion is the most critical factor in determining outcome; the rate of death or severe neurologic injury is low when submerged less than five minutes. Substantial neurologic recovery has been reported following prolonged submersion and anoxia. However, the absence of spontaneous, purposeful movements at 24 hours after drowning is an ominous sign. (See 'Outcome' above.)

REFERENCES

1. Salomez F, Vincent JL. Drowning: a review of epidemiology, pathophysiology, treatment and prevention. Resuscitation 2004; 63:261.
2. National Center for Injury Prevention and Control, Centers for Disease Control and Prevention: WISQARS (web-based injury statistics query and reporting system) [database]. www.cdc.gov/injury/wisqars (Accessed on July 20, 2022).
3. Orlowski JP. Drowning, near-drowning, and ice-water drowning. JAMA 1988; 260:390.

4. Papa L, Hoelle R, Idris A. Systematic review of definitions for drowning incidents. Resuscitation 2005; 65:255.
5. Idris AH, Berg RA, Bierens J, et al. Recommended guidelines for uniform reporting of data from drowning: the "Utstein style". Circulation 2003; 108:2565.
6. Youn CS, Choi SP, Yim HW, Park KN. Out-of-hospital cardiac arrest due to drowning: An Utstein Style report of 10 years of experience from St. Mary's Hospital. Resuscitation 2009; 80:778.
7. Idris AH, Bierens JJLM, Perkins GD, et al. 2015 revised Utstein-style recommended guidelines for uniform reporting of data from drowning-related resuscitation: An ILCOR advisory statement. Resuscitation 2017; 118:147.
8. van Beeck EF, Branche CM, Szpilman D, et al. A new definition of drowning: towards documentation and prevention of a global public health problem. Bull World Health Organ 2005; 83:853.
9. Golden FS, Tipton MJ, Scott RC. Immersion, near-drowning and drowning. Br J Anaesth 1997; 79:214.
10. Vanden Hoek TL, Morrison LJ, Shuster M, et al. Part 12: cardiac arrest in special situations: 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 2010; 122:S829.
11. Beerman S, Bierens JJLM, Clemens T, et al. Clarification and Categorization of Non-fatal D rowning. A draft Position Statement for review and input by the global drowning commu nity. Draft Position Statement, World Health Organization; Workshop on Non-fatal Drow ning, Toronto, Canada, 2018.
12. Brenner RA. Prevention of drowning in infants, children, and adolescents. Pediatrics 2003; 112:440.
13. Quan L, Cummings P. Characteristics of drowning by different age groups. Inj Prev 2003; 9:163.
14. Cohen RH, Matter KC, Sinclair SA, et al. Unintentional pediatric submersion-injury-related hospitalizations in the United States, 2003. Inj Prev 2008; 14:131.
15. Peden MM, McGee K. The epidemiology of drowning worldwide. Inj Control Saf Promot 2003; 10:195.
16. Centers for Disease Control and Prevention (CDC). Drowning--United States, 2005-2009. MMWR Morb Mortal Wkly Rep 2012; 61:344.
17. Schmidt AC, Sempsrott JR, Hawkins SC, et al. Wilderness Medical Society Practice

Guidelines for the Prevention and Treatment of Drowning. Wilderness Environ Med 2016; 27:236.

18. El Sibai R, Bachir R, El Sayed M. Submersion injuries in the United States: Patients characteristics and predictors of mortality and morbidity. Injury 2018; 49:543.
19. Centers for Disease Control and Prevention: Water-related injuries facts. www.cdc.gov/HomeandRecreationalSafety/Water-Safety/waterinjuries-factsheet.html (Accessed on July 20, 2022).
20. Centers for Disease Control and Prevention (CDC). Nonfatal and fatal drownings in recreational water settings--United States, 2001-2002. MMWR Morb Mortal Wkly Rep 2004; 53:447.
21. Bowman SM, Aitken ME, Robbins JM, Baker SP. Trends in US pediatric drowning hospitalizations, 1993-2008. Pediatrics 2012; 129:275.
22. Karaye IM, Farhadi K, Sengstock G, et al. Recent trends in fatal unintentional drowning rates in the United States, 1999-2020. J Safety Res 2023; 84:411.
23. Ellis AA, Trent RB. Hospitalizations for near drowning in California: incidence and costs. Am J Public Health 1995; 85:1115.
24. DeNicola LK, Falk JL, Swanson ME, et al. Submersion injuries in children and adults. Crit Care Clin 1997; 13:477.
25. Dunne CL, Sweet J, Clemens T. The link between medical conditions and fatal drownings in Canada: a 10-year cross-sectional analysis. CMAJ 2022; 194:E637.
26. Olshaker JS. Near drowning. Emerg Med Clin North Am 1992; 10:339.
27. Quan L, Gore EJ, Wentz K, et al. Ten-year study of pediatric drownings and near-drownings in King County, Washington: lessons in injury prevention. Pediatrics 1989; 83:1035.
28. CRAIG AB Jr. Causes of loss of consciousness during underwater swimming. J Appl Physiol 1961; 16:583.
29. Cummings P, Quan L. Trends in unintentional drowning: the role of alcohol and medical care. JAMA 1999; 281:2198.
30. Tester DJ, Kopplin LJ, Creighton W, et al. Pathogenesis of unexplained drowning: new insights from a molecular autopsy. Mayo Clin Proc 2005; 80:596.
31. Diekema DS, Quan L, Holt VL. Epilepsy as a risk factor for submersion injury in children. Pediatrics 1993; 91:612.
32. Brehaut JC, Miller A, Raina P, McGrail KM. Childhood behavior disorders and injuries

among children and youth: a population-based study. Pediatrics 2003; 111:262.

33. Smith GS, Keyl PM, Hadley JA, et al. Drinking and recreational boating fatalities: a population-based case-control study. JAMA 2001; 286:2974.
34. Brenner RA, Saluja G, Smith GS. Swimming lessons, swimming ability, and the risk of drowning. Inj Control Saf Promot 2003; 10:211.
35. Hamilton K, Keech JJ, Peden AE, Hagger MS. Alcohol use, aquatic injury, and unintentional drowning: A systematic literature review. Drug Alcohol Rev 2018; 37:752.
36. Day G, Holck P, Strayer H, et al. Disproportionately higher unintentional injury mortality among Alaska Native people, 2006-2015. Int J Circumpolar Health 2018; 77:1422671.
37. Felton H, Myers J, Liu G, Davis DW. Unintentional, non-fatal drowning of children: US trends and racial/ethnic disparities. BMJ Open 2015; 5:e008444.
38. Clemens T, Moreland B, Lee R. Persistent Racial/Ethnic Disparities in Fatal Unintentional Drowning Rates Among Persons Aged ≤29 Years - United States, 1999-2019. MMWR Morb Mortal Wkly Rep 2021; 70:869.
39. Bell GS, Gaitatzis A, Bell CL, et al. Drowning in people with epilepsy: how great is the risk? Neurology 2008; 71:578.
40. Franklin RC, Pearn JH, Peden AE. Drowning fatalities in childhood: the role of pre-existing medical conditions. Arch Dis Child 2017; 102:888.
41. Kenny D, Martin R. Drowning and sudden cardiac death. Arch Dis Child 2011; 96:5.
42. Bierens JJ, Knape JT, Gelissen HP. Drowning. Curr Opin Crit Care 2002; 8:578.
43. Ibsen LM, Koch T. Submersion and asphyxial injury. Crit Care Med 2002; 30:S402.
44. Karpovich, PV. Water in the lungs in drowned animals. Arch Pathol 1933; 15:828.
45. Giammona ST. Drowning: pathophysiology and management. Curr Probl Pediatr 1971; 1:1.
46. Modell JH. Drowning. N Engl J Med 1993; 328:253.
47. Grmec S, Strnad M, Podgorsek D. Comparison of the characteristics and outcome among patients suffering from out-of-hospital primary cardiac arrest and drowning victims in cardiac arrest. Int J Emerg Med 2009; 2:7.
48. Shattock MJ, Tipton MJ. 'Autonomic conflict': a different way to die during cold water immersion? J Physiol 2012; 590:3219.
49. Dyson K, Morgans A, Bray J, et al. Drowning related out-of-hospital cardiac arrests: characteristics and outcomes. Resuscitation 2013; 84:1114.

50. Battaglia JD, Lockhart CH. Drowning and near-drowning. Pediatr Ann 1977; 6:270.
51. Orlowski JP, Szpilman D. Drowning. Rescue, resuscitation, and reanimation. Pediatr Clin North Am 2001; 48:627.
52. Harries MG. Drowning in man. Crit Care Med 1981; 9:407.
53. Harries M. Near drowning. BMJ 2003; 327:1336.
54. Orlowski JP, Abulleil MM, Phillips JM. The hemodynamic and cardiovascular effects of near-drowning in hypotonic, isotonic, or hypertonic solutions. Ann Emerg Med 1989; 18:1044.
55. Smith R, Ormerod JOM, Sabharwal N, Kipps C. Swimming-induced pulmonary edema: current perspectives. Open Access J Sports Med 2018; 9:131.
56. Brennan CE, Hong TKF, Wang VJ. Predictors of safe discharge for pediatric drowning patients in the emergency department. Am J Emerg Med 2018; 36:1619.
57. Shenoi RP, Allahabadi S, Rubalcava DM, Camp EA. The Pediatric Submersion Score Predicts Children at Low Risk for Injury Following Submersions. Acad Emerg Med 2017; 24:1491.
58. Gonzalez-Rothi RJ. Near drowning: consensus and controversies in pulmonary and cerebral resuscitation. Heart Lung 1987; 16:474.
59. McGillicuddy JE. Cerebral protection: pathophysiology and treatment of increased intracranial pressure. Chest 1985; 87:85.
60. Sarnaik AP, Preston G, Lieh-Lai M, Eisenbrey AB. Intracranial pressure and cerebral perfusion pressure in near-drowning. Crit Care Med 1985; 13:224.
61. Rivers JF, Orr G, Lee HA. Drowning. Its clinical sequelae and management. Br Med J 1970; 2:157.
62. Claesson A, Lindqvist J, Herlitz J. Cardiac arrest due to drowning--changes over time and factors of importance for survival. Resuscitation 2014; 85:644.
63. Omar HR, Sprenker C, Bosco G, et al. Causes of ischemic electrocardiographic changes in near drowning: A literature review. J Crit Care 2015; 30:1121.
64. Vincenzi FF. Drug-induced long QT syndrome increases the risk of drowning. Med Hypotheses 2016; 87:11.
65. Szpilman D. Near-drowning and drowning classification: a proposal to stratify mortality based on the analysis of 1,831 cases. Chest 1997; 112:660.

66. Yagil Y, Stalnikowicz R, Michaeli J, Mogle P. Near drowning in the dead sea. Electrolyte imbalances and therapeutic implications. Arch Intern Med 1985; 145:50.
67. Matsumoto R, Yamada G, Amano A, et al. Hypercalcemic crisis resulting from near drowning in an indoor public bath. Am J Case Rep 2013; 14:210.
68. Mtaweh H, Kochanek PM, Carcillo JA, et al. Patterns of multiorgan dysfunction after pediatric drowning. Resuscitation 2015; 90:91.
69. Hansen LK, Brandslund I, Johannessen D, Andersen PK. Low plasma fibronectin after drowning. Intensive Care Med 1985; 11:100.
70. Fandel I, Bancalari E. Near-drowning in children: clinical aspects. Pediatrics 1976; 58:573.
71. Bonnor R, Siddiqui M, Ahuja TS. Rhabdomyolysis associated with near-drowning. Am J Med Sci 1999; 318:201.
72. Layon AJ, Modell JH. Drowning: Update 2009. Anesthesiology 2009; 110:1390.
73. Mirvis E, Bain BJ. Fresh water-induced hemolysis in near-drowning. Am J Hematol 2022; 97:657.
74. RATH CE. Drowning hemoglobinuria. Blood 1953; 8:1099.
75. Hattesen AL, Berg HK, Folkersen L, Hvas AM. [Drowning-induced hyperfibrinolytic disseminated intravascular coagulation]. Ugeskr Laeger 2017; 179.
76. Schwameis M, Schober A, Schörgenhofer C, et al. Asphyxia by Drowning Induces Massive Bleeding Due To Hyperfibrinolytic Disseminated Intravascular Coagulation. Crit Care Med 2015; 43:2394.
77. Bierens J, Abelairas-Gomez C, Barcala Furelos R, et al. Resuscitation and emergency care in drowning: A scoping review. Resuscitation 2021; 162:205.
78. Venema AM, Groothoff JW, Bierens JJ. The role of bystanders during rescue and resuscitation of drowning victims. Resuscitation 2010; 81:434.
79. Tobin JM, Ramos WD, Pu Y, et al. Bystander CPR is associated with improved neurologically favourable survival in cardiac arrest following drowning. Resuscitation 2017; 115:39.
80. Wyckoff MH, Singletary EM, Soar J, et al. 2021 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations: Summary From the Basic Life Support; Advanced Life Support; Neonatal Life Support; Education, Implementation, and Teams; First Aid Task Forces; and the COVID-19 Working Group. Resuscitation 2021; 169:229.
81. Rosen P, Stoto M, Harley J. The use of the Heimlich maneuver in near drowning: Institute

of Medicine report. J Emerg Med 1995; 13:397.

82. Panchal AR, Bartos JA, Cabañas JG, et al. Part 3: Adult Basic and Advanced Life Support: 2020 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 2020; 142:S366.
83. Ryan KM, Bui MD, Dugas JN, et al. Impact of prehospital airway interventions on outcome in cardiac arrest following drowning: A study from the CARES Surveillance Group. Resuscitation 2021; 163:130.
84. Watson RS, Cummings P, Quan L, et al. Cervical spine injuries among submersion victims. J Trauma 2001; 51:658.
85. Jolly BT, Ghezzi KT. Accidental hypothermia. Emerg Med Clin North Am 1992; 10:311.
86. Richards DB. Drowning. In: Rosen's Emergency Medicine: Concepts and Clinical Practice, 10th, Walls RM, Hockberger RS, Gausche-Hill M, Erickson TB, Wilcox SR (Eds), Elsevier, Philadelphia 2022. Vol 2, p.1815.
87. Kieboom JK, Verkade HJ, Burgerhof JG, et al. Outcome after resuscitation beyond 30 minutes in drowned children with cardiac arrest and hypothermia: Dutch nationwide retrospective cohort study. BMJ 2015; 350:h418.
88. Giesbrecht GG. Cold stress, near drowning and accidental hypothermia: a review. Aviat Space Environ Med 2000; 71:733.
89. Tipton MJ, Golden FS. A proposed decision-making guide for the search, rescue and resuscitation of submersion (head under) victims based on expert opinion. Resuscitation 2011; 82:819.
90. Truhlář A, Deakin CD, Soar J, et al. European Resuscitation Council Guidelines for Resuscitation 2015: Section 4. Cardiac arrest in special circumstances. Resuscitation 2015; 95:148.
91. Quan L, Mack CD, Schiff MA. Association of water temperature and submersion duration and drowning outcome. Resuscitation 2014; 85:790.
92. Champigneulle B, Bellenfant-Zegdi F, Follin A, et al. Extracorporeal life support (ECLS) for refractory cardiac arrest after drowning: an 11-year experience. Resuscitation 2015; 88:126.
93. Coskun KO, Popov AF, Schmitto JD, et al. Extracorporeal circulation for rewarming in drowning and near-drowning pediatric patients. Artif Organs 2010; 34:1026.
94. Dunne B, Christou E, Duff O, Merry C. Extracorporeal-assisted rewarming in the management of accidental deep hypothermic cardiac arrest: a systematic review of the

literature. Heart Lung Circ 2014; 23:1029.

95. Eich C, Bräuer A, Timmermann A, et al. Outcome of 12 drowned children with attempted resuscitation on cardiopulmonary bypass: an analysis of variables based on the "Utstein Style for Drowning". Resuscitation 2007; 75:42.
96. Hilmo J, Naesheim T, Gilbert M. "Nobody is dead until warm and dead": prolonged resuscitation is warranted in arrested hypothermic victims also in remote areas--a retrospective study from northern Norway. Resuscitation 2014; 85:1204.
97. Ruttmann E, Weissenbacher A, Ulmer H, et al. Prolonged extracorporeal membrane oxygenation-assisted support provides improved survival in hypothermic patients with cardiocirculatory arrest. J Thorac Cardiovasc Surg 2007; 134:594.
98. Skarda D, Barnhart D, Scaife E, et al. Extracorporeal cardiopulmonary resuscitation (EC-CPR) for hypothermic arrest in children: is meaningful survival a reasonable expectation? J Pediatr Surg 2012; 47:2239.
99. Svendsen ØS, Grong K, Andersen KS, Husby P. Outcome After Rewarming From Accidental Hypothermia by Use of Extracorporeal Circulation. Ann Thorac Surg 2017; 103:920.
100. Wanscher M, Agersnap L, Ravn J, et al. Outcome of accidental hypothermia with or without circulatory arrest: experience from the Danish Præstø Fjord boating accident. Resuscitation 2012; 83:1078.
101. Choi SP, Youn CS, Park KN, et al. Therapeutic hypothermia in adult cardiac arrest because of drowning. Acta Anaesthesiol Scand 2012; 56:116.
102. Moler FW, Hutchison JS, Nadkarni VM, et al. Targeted Temperature Management After Pediatric Cardiac Arrest Due To Drowning: Outcomes and Complications. Pediatr Crit Care Med 2016; 17:712.
103. Bohn DJ, Biggar WD, Smith CR, et al. Influence of hypothermia, barbiturate therapy, and intracranial pressure monitoring on morbidity and mortality after near-drowning. Crit Care Med 1986; 14:529.
104. Guenther U, Varelmann D, Putensen C, Wrigge H. Extended therapeutic hypothermia for several days during extracorporeal membrane-oxygenation after drowning and cardiac arrest Two cases of survival with no neurological sequelae. Resuscitation 2009; 80:379.
105. de Pont AC, de Jager CP, van den Bergh WM, Schultz MJ. Recovery from near drowning and postanoxic status epilepticus with controlled hypothermia. Neth J Med 2011; 69:196.
106. Soar J, Perkins GD, Abbas G, et al. European Resuscitation Council Guidelines for Resuscitation 2010 Section 8. Cardiac arrest in special circumstances: Electrolyte

abnormalities, poisoning, drowning, accidental hypothermia, hyperthermia, asthma, anaphylaxis, cardiac surgery, trauma, pregnancy, electrocution. Resuscitation 2010; 81:1400.

107. Suen KF, Leung R, Leung LP. Therapeutic Hypothermia for Asphyxial Out-of-Hospital Cardiac Arrest Due to Drowning: A Systematic Review of Case Series and Case Reports. Ther Hypothermia Temp Manag 2017; 7:210.
108. Orlowski JP. Drowning, near-drowning, and ice-water submersions. Pediatr Clin North Am 1987; 34:75.
109. Michelet P, Bouzana F, Charmensat O, et al. Acute respiratory failure after drowning: a retrospective multicenter survey. Eur J Emerg Med 2017; 24:295.
110. Thalmann M, Trampitsch E, Haberfellner N, et al. Resuscitation in near drowning with extracorporeal membrane oxygenation. Ann Thorac Surg 2001; 72:607.
111. Burke CR, Chan T, Brogan TV, et al. Extracorporeal life support for victims of drowning. Resuscitation 2016; 104:19.
112. Bauman BD, Louiselle A, Nygaard RM, et al. Treatment of Hypothermic Cardiac Arrest in the Pediatric Drowning Victim, a Case Report, and Systematic Review. Pediatr Emerg Care 2021; 37:e653.
113. Kim KI, Lee WY, Kim HS, et al. Extracorporeal membrane oxygenation in near-drowning patients with cardiac or pulmonary failure. Scand J Trauma Resusc Emerg Med 2014; 22:77.
114. Ender PT, Dolan MJ. Pneumonia associated with near-drowning. Clin Infect Dis 1997; 25:896.
115. Srámek P, Simecková M, Janský L, et al. Human physiological responses to immersion into water of different temperatures. Eur J Appl Physiol 2000; 81:436.
116. Polderman KH. Mechanisms of action, physiological effects, and complications of hypothermia. Crit Care Med 2009; 37:S186.
117. Stokes RJ, Sayers R, Sieniewicz BJ, Kim WC. Takotsubo cardiomyopathy findings on cardiac magnetic resonance imaging following immersion pulmonary oedema. Diving Hyperb Med 2022; 52:217.
118. Hildebrand CA, Hartmann AG, Arcinue EL, et al. Cardiac performance in pediatric near-drowning. Crit Care Med 1988; 16:331.
119. Kadefors R, Kaiser E, Petersén I. Dynamic frequency analysis of myo-potentials. Electroencephalogr Clin Neurophysiol 1968; 25:402.

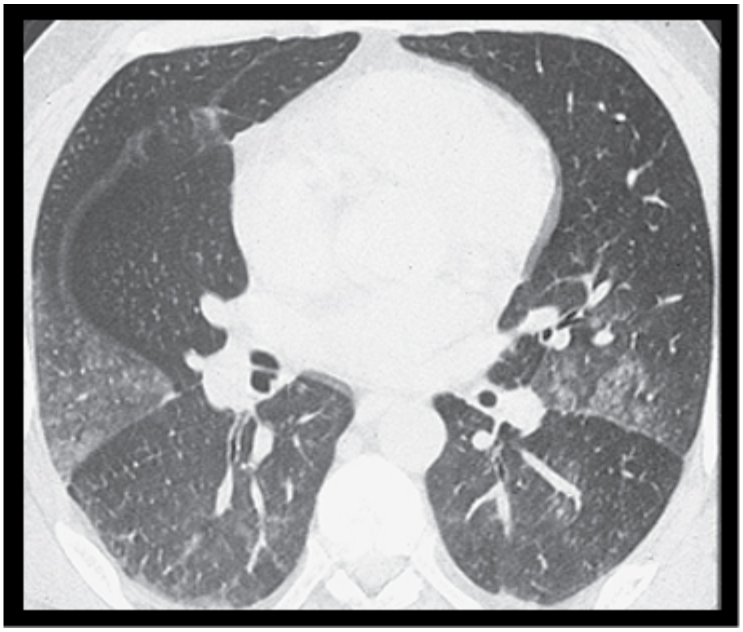
120. Noonan L, Howrey R, Ginsburg CM. Freshwater submersion injuries in children: a retrospective review of seventy-five hospitalized patients. Pediatrics 1996; 98:368.
121. Pratt FD, Haynes BE. Incidence of "secondary drowning" after saltwater submersion. Ann Emerg Med 1986; 15:1084.
122. Causey AL, Tilelli JA, Swanson ME. Predicting discharge in uncomplicated near-drowning. Am J Emerg Med 2000; 18:9.
123. Cohen N, Capua T, Lahat S, et al. Predictors for hospital admission of asymptomatic to moderately symptomatic children after drowning. Eur J Pediatr 2019; 178:1379.
124. Pearn J. Pathophysiology of drowning. Med J Aust 1985; 142:586.
125. Anker AL, Santora T, Spivey W. Artificial surfactant administration in an animal model of near drowning. Acad Emerg Med 1995; 2:204.
126. Varisco BM, Palmatier CM, Alten JA. Reversal of intractable hypoxemia with exogenous surfactant (calfactant) facilitating complete neurological recovery in a pediatric drowning victim. Pediatr Emerg Care 2010; 26:571.
127. Conn AW, Edmonds JF, Barker GA. Cerebral resuscitation in near-drowning. Pediatr Clin North Am 1979; 26:691.
128. Nussbaum E, Maggi JC. Pentobarbital therapy does not improve neurologic outcome in nearly drowned, flaccid-comatose children. Pediatrics 1988; 81:630.
129. Weinstein MD, Krieger BP. Near-drowning: epidemiology, pathophysiology, and initial treatment. J Emerg Med 1996; 14:461.
130. Oakes DD, Sherck JP, Maloney JR, Charters AC 3rd. Prognosis and management of victims of near-drowning. J Trauma 1982; 22:544.
131. Reynolds JC, Hartley T, Michiels EA, Quan L. Long-Term Survival After Drowning-Related Cardiac Arrest. J Emerg Med 2019; 57:129.
132. Reynolds JC, Michiels EA, Nasiri M, et al. Observed long-term mortality after 18,000 person-years among survivors in a large regional drowning registry. Resuscitation 2017; 110:18.
133. Bierens JJ, van der Velde EA, van Berkel M, van Zanten JJ. Submersion in The Netherlands: prognostic indicators and results of resuscitation. Ann Emerg Med 1990; 19:1390.
134. Orlowski JP. Prognostic factors in pediatric cases of drowning and near-drowning. JACEP 1979; 8:176.
135. Biggart MJ, Bohn DJ. Effect of hypothermia and cardiac arrest on outcome of near-drowning accidents in children. J Pediatr 1990; 117:179.

136. Dean JM, Kaufman ND. Prognostic indicators in pediatric near-drowning: the Glasgow coma scale. Crit Care Med 1981; 9:536.
137. Lavelle JM, Shaw KN. Near drowning: is emergency department cardiopulmonary resuscitation or intensive care unit cerebral resuscitation indicated? Crit Care Med 1993; 21:368.
138. Levin DL, Morriss FC, Toro LO, et al. Drowning and near-drowning. Pediatr Clin North Am 1993; 40:321.
139. Quan L, Wentz KR, Gore EJ, Copass MK. Outcome and predictors of outcome in pediatric submersion victims receiving prehospital care in King County, Washington. Pediatrics 1990; 86:586.
140. Suominen P, Baillie C, Korpela R, et al. Impact of age, submersion time and water temperature on outcome in near-drowning. Resuscitation 2002; 52:247.
141. Habib DM, Tecklenburg FW, Webb SA, et al. Prediction of childhood drowning and near-drowning morbidity and mortality. Pediatr Emerg Care 1996; 12:255.
142. Quan L, Bierens JJ, Lis R, et al. Predicting outcome of drowning at the scene: A systematic review and meta-analyses. Resuscitation 2016; 104:63.
143. Christensen DW, Jansen P, Perkin RM. Outcome and acute care hospital costs after warm water near drowning in children. Pediatrics 1997; 99:715.
144. Gonzalez-Luis G, Pons M, Cambra FJ, et al. Use of the Pediatric Risk of Mortality Score as predictor of death and serious neurologic damage in children after submersion. Pediatr Emerg Care 2001; 17:405.
145. Galbiati S, Pastore V, Locatelli F, et al. Neurocognitive and behavioral outcomes in a nearly drowned child with cardiac arrest and hypothermia resuscitated after 43min of no flow-time: A case study. Resuscitation 2017; 118:e3.
146. Bratton SL, Jardine DS, Morray JP. Serial neurologic examinations after near drowning and outcome. Arch Pediatr Adolesc Med 1994; 148:167.
147. Denny SA, Quan L, Gilchrist J, et al. Prevention of Drowning. Pediatrics 2019; 143.
148. Denny SA, Quan L, Gilchrist J, et al. Prevention of Drowning. Pediatrics 2021; 148.
149. O'Flaherty JE, Pirie PL. Prevention of pediatric drowning and near-drowning: a survey of members of the American Academy of Pediatrics. Pediatrics 1997; 99:169.
150. Modell JH. Prevention of needless deaths from drowning. South Med J 2010; 103:650.

Topic 180 Version 38.0

GRAPHICS

CT scan of pulmonary edema due to near-drowning



Ground glass opacities are seen in both upper lobes. In the right lung, ground glass opacities abut the minor fissure and spare the middle lobe.

Courtesy of Paul Stark, MD.

Graphic 57578 Version 2.0

Low tidal volume ventilation in patients with acute respiratory distress syndrome

<table>
<tr><th colspan="9">Initial ventilator settings</th></tr>
<tr><td colspan="9">Calculate predicted body weight (PBW)</td></tr>
<tr><td rowspan="2">Male =</td><td colspan="8">50 + 2.3 [height (inches) - 60] OR</td></tr>
<tr><td colspan="8">50 + 0.91 [height (cm) - 152.4]</td></tr>
<tr><td rowspan="2">Female =</td><td colspan="8">45.5 + 2.3 [height (inches) - 60] OR</td></tr>
<tr><td colspan="8">45.5 + 0.91 [height (cm) - 152.4]</td></tr>
<tr><td colspan="9">Set mode to volume assist-control</td></tr>
<tr><td colspan="9">Set initial tidal volume to 6 mL/kg PBW</td></tr>
<tr><td colspan="9">Set initial ventilator rate ≤35 breaths/min to match baseline minute ventilation</td></tr>
<tr><th colspan="9">Subsequent tidal volume adjustment</th></tr>
<tr><td colspan="9">Plateau pressure goal: Pplat ≤30 cm H_2O</td></tr>
<tr><td colspan="9">Check inspiratory plateau pressure with 0.5 second inspiratory pause at least every four hours and after each change in PEEP or tidal volume.</td></tr>
<tr><td colspan="9">If Pplat $>$30 cm H_2O, decrease tidal volume in 1 mL/kg PBW steps to 5 or if necessary to 4 mL/kg PBW.</td></tr>
<tr><td colspan="9">If Pplat $<$25 cm H_2O and tidal volume $<$6 mL/kg, increase tidal volume by 1 mL/kg PBW until Pplat $>$25 cm H_2O or tidal volume = 6 mL/kg.</td></tr>
<tr><td colspan="9">If breath stacking (autoPEEP) or severe dyspnea occurs, tidal volume may be increased to 7 or 8 mL/kg PBW if Pplat remains ≤30 cm H_2O.</td></tr>
<tr><th colspan="9">Arterial oxygenation and PEEP</th></tr>
<tr><td colspan="9">Oxygenation goal: PaO_2 55 to 80 mmHg or SpO_2 88 to 95 percent</td></tr>
<tr><td colspan="9">Use these FiO_2/PEEP combinations to achieve oxygenation goal:</td></tr>
<tr><th>FiO_2</th><td>0.3</td><td>0.4</td><td>0.5</td><td>0.6</td><td>0.7</td><td>0.8</td><td>0.9</td><td>1.0</td></tr>
<tr><th>PEEP</th><td>5</td><td>5 to 8</td><td>8 to 10</td><td>10</td><td>10 to 14</td><td>14</td><td>14 to 18</td><td>18 to 24</td></tr>
<tr><td colspan="9">PEEP should be applied starting with the minimum value for a given FiO_2.</td></tr>
</table>

Pplat: plateau pressure; PaO_2: arterial oxygen tension; SpO_2: oxyhemoglobin saturation; PEEP: positive end-expiratory pressure; FiO2: fraction of inspired oxygen.

Adapted from: Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. The Acute Respiratory Distress Syndrome Network. N Engl J Med 2000; 342:1301.

Graphic 57072 Version 5.0

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