76 Drowning

David Szpilman, James P. Orlowski, and Joost Bierens

According to the World Health Organization,[1] drowning is a serious and neglected public health threat claiming the lives of more than 372,000 people a year worldwide, or 40 people every hour of every day. More than 90% of these deaths occur in low- and middle-income countries. Whether it is small children slipping unnoticed into a pond, pool, or well; adolescents or others swimming under the influence of alcohol or drugs; passengers on vessels that capsize; or residents of coastal communities struck by floods, the toll of this global killer continues its quiet rise.

Fatal drowning is a frequent cause of death worldwide among boys 5 to 14 years of age. In the United States, drowning is the second leading cause of injury-related death among children 1 to 4 years of age, with a death rate of 3 per 100,000. In some countries, including Thailand, the death rate among 2-year-old children is more than 100 per 100,000.[2]

International data severely underestimate actual drowning figures, even for high-income countries.[3] Epidemiologic data account for only 6% of the problem because drowning deaths are not registered in many countries. Almost all drowning victims are able to help themselves or are rescued in time by bystanders or professional rescuers. In areas where lifeguard services fully operate,[2] fewer than 1% of all persons rescued by lifeguards need cardiopulmonary resuscitation (CPR), and 0.3% of the rescues resulted in the death of the victim (0.34%).[4] In one report of rescues by bystanders, almost 30% of persons rescued from drowning required CPR,[5] demonstrating that a delay in intervention may lead to a more severe outcome than where lifeguards are on duty. Unfortunately, lifeguard or layperson rescues and first aid attendance are rarely considered in national databases, resulting in a distorted picture of drowning burden worldwide.

From 1972 to 2002 the Fire Department of Rio de Janeiro—Lifeguard Service (CBMERJ) made approximately 166,000 rescues on the beaches, and 8500 victims required attendance by the medical team in the Drowning Resuscitation Centre. With this scenario of a full lifeguard service in operation, approximately 290 rescues for each death (0.34%) were reported and one death for each 10 victims admitted for medical care in the Drowning Resuscitation Center (DRC).

The bias produced by not accounting for actual drowning figures affects not only the relative epidemiologic importance related to the problem of drowning[6] but also gives the false impression that every drowning requires CPR and that to know how to resuscitate is the most important tool to save people from drowning.

Coastal drownings are estimated to cost more than $273 million per year in the United States and more than $228 million per year (in U.S. dollars) in Brazil. For every person who dies from drowning, another four receive care in the emergency department for nonfatal drowning.[1] Exposure-adjusted, person-time estimates for drowning are 200 times higher than deaths from traffic accidents.[7]

Key risk factors for drowning are male sex, age of less than 14 years, alcohol use, low income, poor education, rural residency, aquatic exposure, risky behavior, and lack of supervision. For people with epilepsy, the risk of drowning is 15 to 19 times the risk of those without.[1]

Drowning deaths can be prevented in over 85% of cases by using a series of interventions.[8] When preventive measures fail, responders need to be able to perform the necessary steps to interrupt the pathophysiologic processes associated with drowning. The first challenge is to recognize someone in the water at risk of drowning and appreciate the need for rescue. Early self-rescue or rescue by others may stop the drowning process and prevent initial and subsequent water aspiration, respiratory distress, and medical complications. The drowning process happens quickly, but it is critical that rescuers take precautions not to become another victim by engaging in inappropriate or dangerous rescue responses.[5,9] Removing the victim from a hostile environment has major potential for harm to the rescuer. The "drowning chain of survival"[10] refers to a series of water safety interventions that when put into action by lay or professionals reduce the mortality associated with drowning.

DEFINITION

A new definition of drowning was adopted by the World Health Organization in 2002,[11] stating that "Drowning is the process of experiencing respiratory impairment from submersion or immersion in liquid."

The drowning process is a continuum, beginning with respiratory impairment as the victim's airway goes below the surface of the liquid (submersion) or when water splashes over the face (immersion). If the victim is rescued at any time, the process of drowning is interrupted, and this is called *nonfatal drowning*. If the victim dies at any time, this is a *fatal drowning*. Any submersion or immersion incident without evidence of respiratory impairment should be considered a water rescue and not a drowning. Terms such as "near-drowning," "dry or wet drowning," "secondary drowning," "active and passive drowning," and "delayed onset of respiratory distress" should not be used.[11] A uniform way to report data for studies on drowning and to allow comparison between different centers is to adopt the Utstein template for drowning resuscitation cases.[12]

PATHOPHYSIOLOGY

When water is aspirated into the airways, coughing occurs as an initial reflex response. In less than 2% of cases,[13,14] laryngospasm may be present when the victim starts to inhale water. If the person is not rescued, aspiration of water continues, and hypoxemia leads to loss of consciousness and apnea. Apnea and hypoxia precede cardiac arrest. As a consequence, hypoxic cardiac arrest generally occurs after a period of bradycardia and pulseless electrical activity (PEA) and not by means of ventricular fibrillation.[15,16] The process from immersion to cardiac arrest occurs in seconds to minutes depending on the scenario, but in unusual situations, such as when hypothermia preceeds hypoxia, this process can last for up to an hour.[17] In most drowning cases, cardiac function is initially relatively preserved and only ceases perfusion due to hypoxic insult after a period of apnea.[4,9]

If the person is rescued in time during the drowning process, the clinical picture is determined by the reactivity of the airways and the amount of water that has been aspirated. Water in the alveoli causes surfactant destruction and wash-out. Salt and fresh water aspiration causes similar pathology.[15] In either situation, the effect of the osmotic gradient on the alveolar-capillary membrane can disrupt its integrity, increase permeability, and exacerbate fluid, plasma, and electrolyte shifts.[15] The clinical picture of damage is regional or generalized pulmonary edema (depending on the amout of water aspirated and airway reactivity) that may alter exchange of O_2 and CO_2.[4,15,18] In animal experiments,[18] aspiration of 2.2 mL of water per kilogram of body weight leads to severe disturbance of oxygen exchange, decreasing arterial oxygen pressure (PaO_2) to approximately 60 mm Hg within 3 minutes. In humans, it seems that as little as 1 to 3 mL/kg of water aspiration produces profound alterations in pulmonary gas exchange and decreases pulmonary compliance by 10% to 40%.[15] The combined effects of fluids in the lungs, loss of surfactant, and increased capillary-alveolar permeability can result in decreased lung compliance, increased right-to-left shunting in the lungs, atelectasis, and alveolitis.[15]

DROWNING CHAIN OF SURVIVAL (FIG. 76-1)[10]

Prevent Drowning

The most effective way to reduce the number of drowning deaths is prevention. It has been estimated that 80% to 90% of all drownings are preventable.[8,19] Drowning prevention requires multiple factors (Table 76-1).

Recognize Distress and Call for Help

The second element in the drowning chain is to recognize a person in distress in the water and know how to activate help.[21] The Drowning Risk Assessment (DRA) identifies a person at high risk of drowning by a near-vertical body position, ineffective downward arm movements, ineffective pedaling or kicking leg actions, and little or no forward progress in the water. Professionals trained in DRA easily identify persons at risk of drowning. Sending someone to call for help upon recognizing a person in water distress is a key element that ensures early activation of professional rescue service and EMS.[10]

Provide Flotation to Stop the Process of Drowning[10]

The next priority is to interrupt the drowning process by providing flotation to the victim as an interim measure to reduce submersion risk. This buys valuable time for those on scene to initiate rescue efforts and for emergency services to arrive. Devices such as ring buoys are purposely designed to provide flotation; however, they are only available at very few locations where a drowning occurs. In most situations, improvised buoyancy aids, such as empty plastic bottles, containers, ice chests, or driftwood, should be used. It is critical that laypersons take precautions not to become another victim by engaging in inappropriate or dangerous rescue responses.[5,9] Reaching out with, throwing, or dropping the buoyancy aid without entering the water is the preferred method of providing flotation to a drowning victim.[24] Also, because many victims cling to their would-be rescuer, it is better to approach a struggling victim with an intermediary object.

In-Water Resuscitation[25]

If not interrupted, the drowning process leads first to unconsciousness and apnea, followed by cardiac arrest within minutes. During this short window of opportunity, immediate in-water ventilation may provide benefit if provided safely and effectively. For the unconscious victim, in-water resuscitation can increase the rates of discharge from hospital without sequelae by more than threefold. In-water ventilation is only possible if the rescuer is highly trained. Chest compression while the rescuer and victim are in deep water is futile, so assessment for a pulse does not serve any purpose. Victims with only respiratory arrest usually respond after a few rescue breaths. If there is no response, the

TABLE 76-1 Preventive Measures

Watch children carefully; 84% of drownings occur because of inadequate adult supervision. Begin swimming lessons from 2 years of age.
Avoid inflatable swimming aids such as "floaties" as they can give a false sense of security. Use lifejackets!
Never try to help rescue someone without being able to do it. Many people have died trying to do so.
Avoid drinking alcohol and eating lunch before swimming.
Don't dive in shallow water, as cervical spine injury could occur.

BEACHES	POOLS AND SIMILAR BODIES OF WATER
Always swim in a lifeguard-supervised area.	Over 65% of deaths occur in fresh water, even on the coast.
Ask the lifeguard for safe places to swim or play.	Fence off your pool and include a gate.
Read and follow warning signs posted on the beach.	Recommended, approved fencing can decrease drowning by 50% to 70%.
Do not overestimate your swimming capability—46.6% of drowning victims thought they knew how to swim.	Avoid toys around the pool.
Swim away from piers, rocks, and stakes.	Whenever infants or toddlers are in or around water, be within arm's length, providing "touch supervision."
Take lost children to the nearest lifeguard tower.	Turn off motor filters when using the pool.
Over 80% of drownings occur in rip currents (the rip is usually the most falsely calm, deep place between two sand bars). If caught in a rip, swim transversally to the sand bar or let it take you away without fighting and wave for help.	Always use portable phones in pool areas, so you are not called away to answer.
If you are fishing on rocks, be careful about waves that may sweep you into the ocean.	Don't try to hyperventilate to increase submersion time.
Keep away from marine animals.	Use warning sign of shallow water in the pool.
	Learn CPR; over 42% of pools owners are not aware of first aid techniques. Be careful!

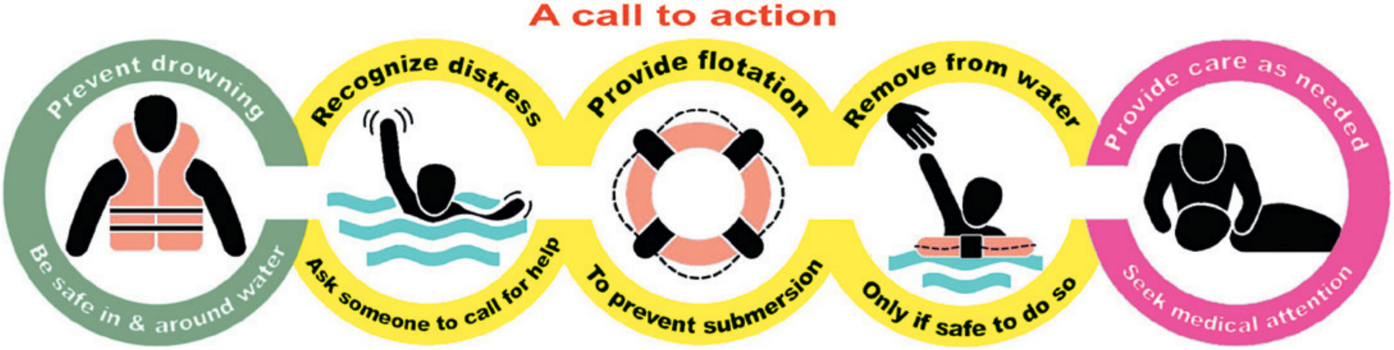


FIGURE 76-1 ■ Drowning chain of survival. (Adapted from Szpilman D, Morizot-Leite L, Vries W, et al. First aid courses for the aquatic environment. In: Bierens JJ, ed. Handbook on Drowning: prevention, rescue, and treatment. Berlin: Springer-Verlag; 2006, p. 342–7.)

victim should be assumed to be in cardiac arrest and be moved as quickly as possible to dry land where effective CPR can be initiated.

Cervical Spine Injury

Very few studies have examined how often in-water cervical spine injury (CSI) occurs.[26-28] One such study retrospectively evaluated 46,060 water rescues on sand beaches and demonstrated that the incidence of CSI in this setting was very low (0.009%).[27] In another retrospective survey of more than 2400 drowning cases, only 11 (<0.5%) had CSI, and all had a history of obvious trauma from diving, falling from height, or a motor vehicle accident.[26] Considering this low incidence of CSI and the high risk to wasted time when ventilation is needed, routine cervical spine immobilization of water rescues without reference to whether a traumatic injury was sustained is not recommended.[29] Therefore, no attempt to immobilize the spine should be made without a strong indication and certainly not in cases where the victim appears lifeless.[30]

Remove from Water: Rescue Only if Safe to Do So

The attempt to perform a rescue typically involves three phases: approach, contact, and stabilizing the victim. Removing the victim from water is essential to end the drowning process[25] and allows a setting for better assessment and care of the victim. Several strategies for removal can be used by bystander rescuers. The victim can be helped by directing them to the closest and safest place to get out of the water. If everything else fails, the lay rescuer may consider entering the water to attempt to rescue the victim by throwing, reaching, or wading to the victim.[10] To mitigate risk to the bystander rescuer, the use of some type of flotation or a connecting rope is recommmended, although sometimes these devices can also increase the risk.[24] To enter the water is a personal decision and may depend on the personal relationship with the victim (e.g., parents and children), water depth, distance to swim, and swimming skills.

The position of a drowning victim for transport out of the water is preferably as near to horizontal as possible but with the head still maintained above body level (keep horizontal if prolonged immersion or a history of immersion in cold water). The airways should be kept open at all times, if possible.[31]

Provide Care as Needed

Basic Life Support

Once on land, the victim should be placed supine with trunk and head at the same level. On beaches, this means parallel to the shore line. The standard checks for responsiveness and breathing are carried out.[25] If unconscious but breathing, the recovery position should be used.[31] If the victim is not breathing, ventilation is essential.[2,4,30] If the victim has a cardiac arrest from drowning, this is primarily due to lack of oxygen.[4,9,30,32] For this reason, it is important that CPR follows the traditional Airway-Breathing-Circulation (ABC)[32,33] sequence. Upper airway management is often challenging due to vomiting and the presence of pulmonary edema fluid that interferes with airway management, while at the same time pulmonary injury makes initial ventilation difficult because of decreased pulmonary compliance.[30,35] Ventilation should be started with 5 initial breaths followed by 30 chest compressions and then continued with two breaths to 30 compressions until signs of life reappear, rescuer exhaustion occurs, or ALS becomes available. Because cardiac arrest in drowning victims is caused by asphyxia, cardiac compression-only CPR is useless.[30,32]

The most frequent complication during drowning resuscitation is regurgitation of stomach contents, which occurs in more than 65% of victims who need rescue breathing alone, and in 86% of victims who require CPR.[36] The presence of vomitus in the airway can result in further aspiration injury and impairment of oxygenation.[25] Active efforts to expel water from the airway (abdominal thrusts or placing the victim head down) should be avoided as they only delay the initiation of ventilation, increase the risk of vomiting by more than five-fold, and thereby lead to a significant increase in mortality.[25,31]

A study has shown that less than 10% of all drowning victims are in ventricular fibrillation.[37] Given this, the effectiveness of an automated external defibrillator (AED) during drowning is low.

Advanced Life Support

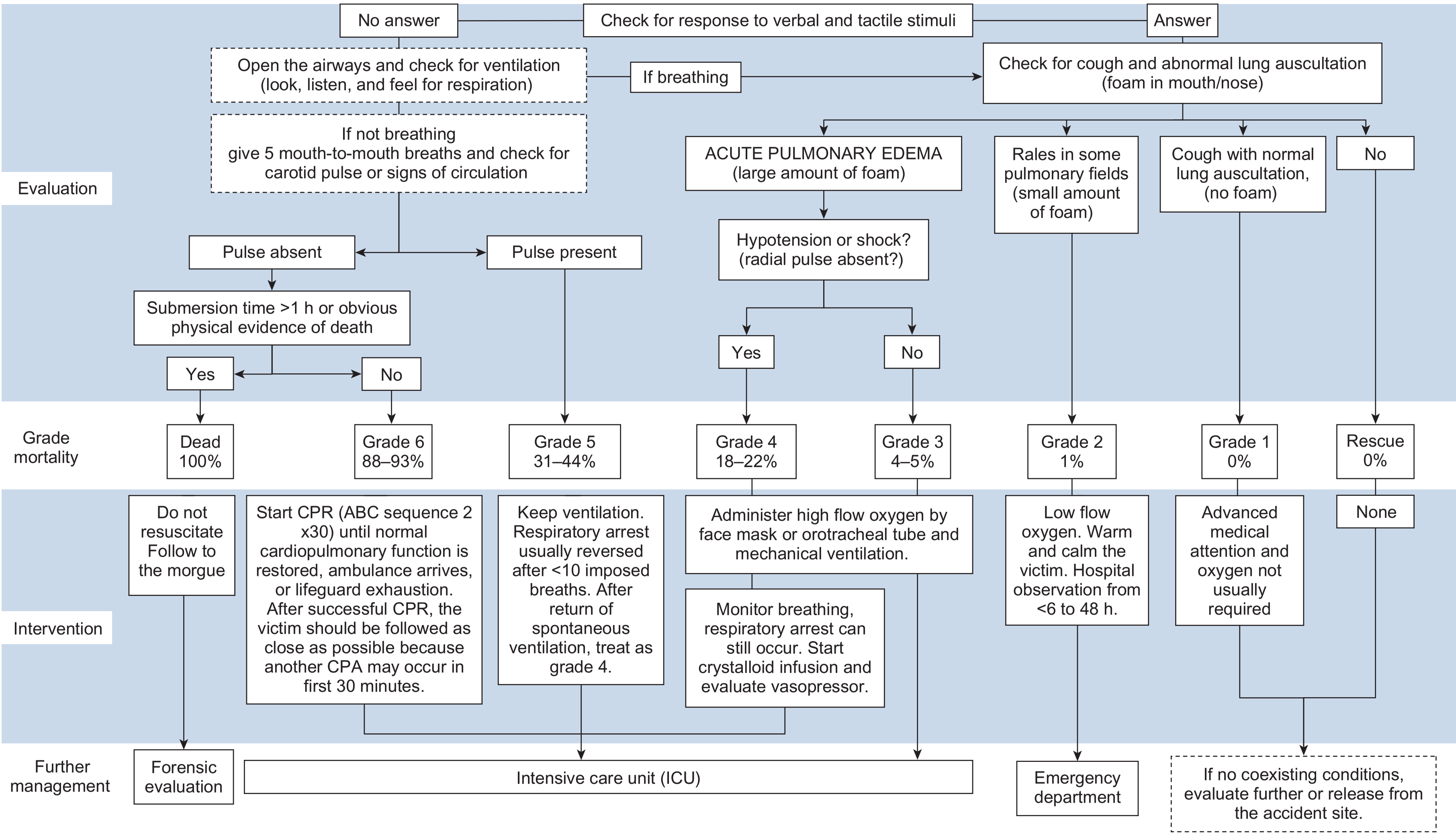
Drowning Severity Classification. Early basic life support contributes to better outcomes from drowning and should be initiated as soon as possible.[2] Cardiopulmonary or isolated respiratory arrest comprises only approximately 0.5% of all rescues. In this situation, it is clear that CPR has to be started. For less serious situations, a classification system has been developed in Rio de Janeiro (Brazil) in 1972 and updated in 1997[4] to assist lifeguards, ambulance personnel, and physicians in treatment of drowning victims. This classification was initially based on an analysis of 41,279 rescues, of which 2304 (5.5%) needed medical attention and then revalidated in 2002 by another 10-year study that included 46,080 rescues.[38] This classification (Fig. 76-2)[2] is stratified into 6 grades plus a rescue and a nonresuscitation condition encompassing support from the site of the accident to the hospital. The classification system recommends the most appropriate treatment and shows the likelihood of death based on the severity of injury. Severity is easily accessed by an on-scene rescuer, EMT, or physician using only clinical variables.[4]

To save time, medical equipment should be brought to the victim instead of the victim to the ambulance. Advanced medical treatment is given according to drowning classification.[4,10] Recommendations for when to start and stop resuscitation are different from nondrowning-related cardiac arrest (Table 76-2).[2,16]

For grade 6 cases (cardiopulmonary arrest[4]), resuscitation started by a layperson or lifeguard at the scene must be continued by the EMS system. The first priority should be adequate oxygenation and ventilation using bag-mask ventilation with 15 liters of oxygen until an orotracheal tube can be inserted. Meanwhile, cardiac compression should be continued. Once intubated, most victims can be oxygenated and ventilated effectively even in situations where copious pulmonary edema fluid fills the endotracheal tube. Suctioning of the orotracheal tube should be performed only when the presence of fluid makes effective ventilation impossible. Suctioning can disturb oxygenation and should be balanced against the need to ventilate and oxygenate. For cardiac monitoring, the presenting rhythm in cases of cardiac arrest following drowning is usually asystole or pulseless electrical activity (PEA). Ventricular fibrillation is rarely reported but may occur if there is a history of coronary artery disease, use of epinephrine, or in the presence of severe hypothermia.[16] If ventricular fibrillation is present, defibrillation should be attempted. Peripheral venous access is the preferred route for drug administration in the prehospital setting. Endotracheal administration of drugs is not recommended for drowning.[34] Doses of 1 mg epinephrine IV (or 0.01 mg/kg) can be considered. After the resuscitation process is well organized, an orogastric tube can

TABLE 76-2 Drowning: When to Initiate CPR and When to Discontinue[2]

QUESTION	RECOMMENDATIONS
In whom to begin?	Give ventilatory support for respiratory distress/arrest to avoid cardiac arrest. Start CPR in all submersions <60 minutes who do not present with obvious physical evidence of death.
When to discontinue?	Basic life support should continue unless signs of life reappear, rescuers are exhausted, or advanced life support can take over. Advanced life support should be ongoing until patient has been rewarmed (if hypothermic) and asystole persists for more than 20 minutes.



Abbreviations: CPR (cardiopulmonary resuscitation); CPA (cardiopulmonary arrest); recovery position (lateral decubitus position). Lay classification of severity terminology in bracket.

FIGURE 76-2 ■ Drowning severity classification and flow chart strategy decision based on evaluation of 87,339 rescues.[2,4,38]

be placed to reduce gastric distention and prevent further aspiration. This is particularly indicated if abdominal distention restricts ventilation. If initial resuscitation efforts are not successful, the victim should be transported to a hospital where advanced warming measures can be accomplished while resuscitation is continued during transport.

Grade 5 cases (isolated respiratory arrest[4]) are usually reversed by bystanders or lifeguards by the time advanced life support arrives at the scene. If not previously done, oxygenation and ventilation protocols as for grade 6 should be followed until spontaneous breathing is restored. If there is spontaneous ventilation, the protocol for grade 4 is followed. A grade 4 (acute pulmonary edema with hypotension[4]) patient may initially be able to maintain adequate oxygenation, although the respiratory rate is frequently elevated. Oxygenation goals are to achieve a prehospital peripheral saturation above 92% by administering oxygen by face mask at a rate of 15 L/min. Early intubation and mechanical ventilation are indicated for respiratory fatigue, even when good oxygenation is achieved using the face mask. Once intubated, most victims can be oxygenated and ventilated effectively. Patients should be sedated to tolerate intubation, and artificial mechanical ventilation providing a tidal volume of at least 5 mL/kg of body weight. FiO_2 can initially be 1.0 but should be reduced when possible. If hypotension is not corrected by oxygen, a rapid crystalloid infusion should be used.[15]

In grade 3 cases (acute pulmonary edema without hypotension), a therapeutic decision relates to whether there would be more benefit with initiating invasive ventilation rather than using face mask oxygenation. Only 27.6% of grade 3 drowning victims can be supported with noninvasive ventilatory support. Grade 2 patients (abnormal auscultation with rales in some pulmonary fields) usually require only oxygen by nasal cannula. In grade 1 and rescue cases, advanced medical attention and oxygen are not usually required.

As the majority of drowning victims has only mild distress or may not actually aspirate water, it is important for responders to know when to call EMS or seek medical assistance/hospital care (Table 76-3). Emergency department evaluation is recommended for all patients of grade 2 to 6 drowning.

Hospital. Decision making regarding admission to an intensive care unit (ICU) or hospital bed versus observation in an emergency department or discharge home should include a thorough history of the incident and previous illness, physical examination, and diagnostic studies including chest radiography and ABG measurement. Electrolytes, blood urea nitrogen, creatinine, and hemoglobin also should be assessed, although perturbations in these laboratory tests are unusual. In some cases, a toxicologic screen for suspected alcohol, recreational drug use, or drug overdose might be warranted. Patients who experienced grade 3 to 6 drowning should be admitted to an ICU for close observation and therapy. Grade 2 patients can be observed in the emergency room for 6 to 24 hours, but grade 1 and rescue cases with no complaints or associated illness or trauma can be released home.

Drowning is sometimes precipitated by an injury or medical condition such as trauma, seizure, or cardiac arrhythmia. Such comorbidities should be considered[4] after arrival in the emergency department, as they affect treatment options.

Respiratory Concerns. Grade 4 to 6 patients will usually arrive from prehospital advanced life support on mechanical ventilation with acceptable oxygenation. If not, the emergency department physician should follow standard ventilation protocols. Positive end-expiratory pressure (PEEP) should be added initially at a level of 5 cm H_2O and then increased by 2- to 3-cm H_2O increments as needed until the intrapulmonary shunt (QS : QT) is 20% or less, or $PaO_2 : FiO_2$ of 250 or more is achieved. A clinical picture very similar to acute respiratory distress syndrome (ARDS) is common after significant drowning episodes (grade 3 to 6). Management is similar to that of other patients with ARDS, including efforts to minimize volutrauma and barotrauma. Lung-protective ventilation involving permissive hypocapnia probably is not suitable for drowning victims with grade 6 severity that may be associated with significant hypoxic-ischemic brain injury. In selected cases, CPAP may be provided by mask in cooperative adolescents or by nasal cannula in infants who are obligate nasal breathers, but usually this is not tolerated. If pulmonary and psychological status allows the patient to breathe without fighting, continuous positive airway pressure (CPAP) or a ventilatory pressure support mode (PSV) can be a good choice.

Pools, rivers, and beaches generally have insufficient bacteria colonization to induce pneumonia in the immediate postdrowning period.[39] Pneumonia is often initially misdiagnosed because of the early radiographic appearance of water in the lungs.[40] If the patient needs mechanical respiratory assistance, the incidence of ventilator-associated pneumonia increases from 34% to 52% in the third or fourth day of hospitalization as pulmonary edema is resolving.[40] Vigilance not only for pulmonary but also other infectious complications is important. Prophylactic antibiotics tend to only select out more resistant and more aggressive organisms.[42] Daily monitoring of tracheal aspirates for Gram stain, culture, and sensitivity is advised. At the first sign of pulmonary infection, usually during the first 48 to 72 hours after drowning (as indicated by fever, sustained leukocytosis, persistent or new pulmonary infiltrates, and increased leukocyte numbers in tracheal aspirates), antibiotic therapy can be initiated using information, if available, on the predominant organism in the water where the drowning occurred. If there are reasons to suspect ventilator-associated pneumonia, antibiotics should be directed to the sensitivity of the predominant microorganisms in the ICU or by cultures if available. Fiberoptic bronchoscopy may be useful for evaluation of infection and for the rare occasions where therapeutic clearing of sand, gravel, or other solids is indicated. Corticosteroids for pulmonary injury should not be used except for bronchospasm.

The clinician must be aware of and constantly be vigilant for volutrauma and barotrauma during ventilation of drowning victims.[39] Spontaneous pneumothoraces are common (10%) secondary to positive-pressure ventilation and local areas of hyperinflation. Any sudden change in hemodynamic stability after mechanical ventilation is initiated should be considered to be due to pneumothorax or other barotrauma until proven otherwise.

Circulatory Issues. Cardiac dysfunction with low cardiac output is common immediately after severe drowning.[15] Low cardiac output

TABLE 76-3 Who Needs Further Medical Help After Rescue from the Water

(a) A patient who has experienced or required any of the following should be sent to a hospital:
- Loss of consciousness, even for a brief period
- Rescue breathing
- Cardiopulmonary resuscitation
- A serious condition such as heart attack, spinal injury, other injury, asthma, epilepsy, stinger, intoxication, delirium

(b) The following persons may be considered for release from care at the scene if, after 10-15 minutes of careful observation while being warmed with blankets or other coverings as required, the patient has ALL of the following:
- No cough
- Normal rate of breathing
- Normal circulation as measured by pulse in strength and rate and blood pressure (if available)
- Normal color and skin perfusion
- No shivering
- Is fully conscious, awake and alert

In such cases, it is unwise for the patient to drive a vehicle, and the patient should be so advised. If any of these conditions does not apply or if the lifesaver has any doubt, then the patient should be advised to seek early medical attention.

(c) There is always a risk of delayed lung complications. All immersion victims should therefore be warned that if they later develop cough, breathlessness, fever, or any other concerning respiratory symptoms, they should seek medical advice immediately. It is preferable that these persons not return to a home environment where they are alone for the next 24 hours.

is associated with high pulmonary capillary occlusion pressure, high central venous pressure, and high pulmonary vascular resistance and can persist for days after correction of oxygenation and perfusion abnormalities in drowning victims. This may add a cardiogenic component to drowning-associated pulmonary edema. Low blood pressure, if present, can be corrected with better oxygenation, rapid crystalloid infusion, and restoration of normal body temperature. Vasopressor infusion should be used only in refractory hypotension to improve cardiac output when replacement with crystalloid is inadequate to restore blood pressure. Urine output should be monitored by means of a Foley catheter. Echocardiography to assess cardiac function and ejection fraction can help to guide the clinician in titrating inotropic agents, vasopressors, or both if volume crystalloid replacement has failed.[2] In patients who are hemodynamically unstable or have severe pulmonary dysfunction, pulmonary artery catheterization may be considered to provide information concerning Starling forces in the lungs and may help in managing pulmonary edema. When pulmonary edema occurs after drowning, there is no evidence to support the use of any specific fluid therapy for salt and fresh water drowning,[15] diuretics or water restriction.

Metabolic acidosis occurs in 70% of patients arriving at the hospital after a drowning episode.[4] Acidosis should be corrected when pH is lower than 7.2 or bicarbonate is less than 12 mEq/L in spite of adequate ventilatory support. Significant depletion of bicarbonate is rarely present in the first 10 to 15 minutes of CPR, and its use is not indicated in the initial resuscitation period. In hypothermic patients, arterial blood gases do not need to be temperature corrected (the alpha-stat or pH-stat concept).[43]

Neurologic System. The most important complication in grade 6 drowning, beyond reversible pulmonary injury, is anoxic-ischemic cerebral insult. Most late deaths and long-term sequelae of drowning are neurologic in origin.[39] Although the highest priority in resuscitation after drowning is restoration of spontaneous circulation, every effort in the early stages after rescue should also be directed at resuscitating the brain and preventing further neurologic damage. These steps include providing adequate oxygenation (SaO_2p > 92%) and cerebral perfusion (mean arterial pressure around 100 mm Hg). Any victim who remains comatose and unresponsive after successful CPR or deteriorates neurologically should undergo careful and frequent neurologic function assessment for the development of cerebral edema and should be treated with the following measures:

- Raise the head of the bed by 30 degrees (if there is no hypotension).
- Maintain adequate mechanical ventilation.
- Ensure appropriate respiratory toilet without provoking hypoxia.
- Treat for seizure activity if present.
- Avoid overly rapid correction of metabolic alterations.
- Prevent interventions that increase intracranial pressure (ICP), including urinary retention, pain, hypotension, and hypoxia, by using sedation or muscular relaxants as necessary.
- Hyperthermia should be prevented in the acute recovery period.
- Frequently monitor blood glucose concentration, and maintain normoglycemic values.[44]

Frequent monitoring of temperature is recommended in the emergency department and intensive care unit. Drowning victims with restoration of adequate spontaneous circulation who remain comatose should not be actively rewarmed to temperatures above 32°C to 34°C. If core temperature exceeds 34°C, therapeutic hypothermia (32°C-34°C) should be achieved as soon as possible and sustained for 12 to 24 hours. Although there is insufficient evidence to support a specific target $PaCO_2$ or oxygen saturation during and after resuscitation, hypoxemia should be avoided. Unfortunately, studies evaluating the results of cerebral resuscitation measures in drowning victims have failed to demonstrate that therapies directed at controlling intracranial hypertension and maintaining artificially high cerebral perfusion pressure (CPP) improve outcome. These studies have shown poor outcomes (i.e., death or moderate to profound neurologic sequelae) when the intracranial pressure was 20 mm Hg or more and the CPP was 60 mm Hg or less, even when therapies were directed at controlling and improving these pressures.

Ice-Water Drowning. In some cases, hypothermia is just a reflection of prolonged submersion time and a bad prognosis. In other victims, early hypothermia is an important reason why survival without neurological damage is possible.[30,45] Recent reports on drowning have documented good outcomes in postresuscitation patients who were kept hypothermic or treated with therapeutic hypothermia despite predicted poor outcome.[32,46,47] Hypothermia associated with drowning can provide a protective mechanism that allows victims to survive prolonged submersion episodes.[2,17] The rate of cerebral oxygen consumption is reduced by approximately 5% per each °C decrease in temperature within the range of 37°C to 20°C.[48]

The paradox in drowning resuscitation is that the hypothermic victim needs to be warmed in order to effectively resuscitate but then may benefit from induced therapeutic hypothermia after successful resuscitation.[2] An important dictum that has been developed from experience with ice-water drownings and accidental hypothermia is that victims who appear dead after exposure to very cold temperatures should not be pronounced dead until they are at near-normal core temperature and remain asystolic.

Several studies have shown benefit from new therapeutic interventions for drowning victims such as extracorporeal membrane oxygenation,[46] artificial surfactant, and nitric oxide.[49]

Unusual Complications. Important medical complications after drowning, other than those associated with neurologic function, are rare and are almost all restricted to patients with grade 6 severity. Rarely, some drowning victims who have normal chest radiography at initial assessment in the ED develop fulminant pulmonary edema as long as 12 h after the incident. Whether this late-onset pulmonary edema is ARDS, a neurogenic pulmonary edema secondary to hypoxia, or just an airway hypereactive to water aspiration is unclear. Renal insufficiency or renal failure is rare in drowning victims but can occur secondary to anoxia, shock, or hemoglobinuria.

OUTCOME AND SCORING SYSTEMS

With advances in intensive care therapy, prognostication for drowning victims is now primarily based on neurologic outcome.[9] Of the drowning victims with grade 1 to 5 severity, 95% return home without sequelae.[4]

In patients with grade 6 severity, prognostic variables are important when counseling family members in the early stages after the drowning incident and in deciding which patients are likely to have a good outcome with standard supportive therapy and which should be candidates for intensive cerebral resuscitation therapies.[9]

Victims who remain comatose or deteriorate neurologically should undergo intensive assessment and care.[50] Questions such as "How can we know for whom we should make the effort to resuscitate? How long should we continue to resuscitate? How should treatment differ? What should we expect as life quality after successful resuscitation?" need to be answered. Both at the rescue site and in the hospital, no single indicator for grade 6 severity appears to be an absolutely reliable predictor of outcome.[2] Prolonged submersion with successful resuscitation is not only possible in cold or icy water, as some anecdotal cases of warm-water drowning survival without sequelae have been described.[4,45,51] Multiple studies[2,4,9,12,16,17,19,25,48,50,51] have established that the outcome is almost solely determined by a single factor—duration of submersion. Basic and advanced life support enable victims to achieve their best outcome possible when the duration of cardiopulmonary arrest (submersion time included) is minimized. Most patients who show improvement and are alert (or are stuporous or obtunded but respond to stimuli 2 to 6 hours after the incident) have normal or near-normal neurological outcomes (Table 76-4).[9]

TABLE 76-4 Clinical Prognostic Score for the Immediate Period After Successful CPR Based on Glasgow Coma Score[9]

NEUROLOGIC PROGNOSTIC SCORE AFTER SUCCESSFUL CPR UPON DROWNING

A: FIRST HOUR	B: AFTER 5 TO 8 H
Alert, 10	Alert, 9.5
Confused, 9	Confused, 8
Torpor, 7	Torpor, 6
Coma with normal brainstem functions, 5	Coma with normal brainstem functions, 3
Coma with abnormal brainstem functions, 2	Coma with abnormal brainstem functions, 1

A + B RECOVERY WITHOUT SEQUELAE

Excellent, ≥13	≥95%
Very good, 10-12	75% to 85%
Good, 8	40% to 60%
Regular, 5	10% to 30%
Poor, 3	≤5%

KEY POINTS

1. Drowning is a serious and neglected public health threat claiming the lives of 372,000 people per year worldwide.
2. Data account for only 6% of the cases, almost all resulting in death, giving the false impression that every drowning requires CPR and that knowing how to resuscitate is the most important tool.
3. Exposure-adjusted, person-time estimates for drowning deaths are 200 times higher than such estimates for deaths from traffic accidents.
4. The "drowning chain of survival" refers to a series of water-safety interventions that, when put into action, reduce the morbidity and mortality associated with drowning.
5. Drowning deaths can be prevented in over 85% of cases.
6. When prevention fails, the first challenge is to recognize someone in the water at risk of drowning, to appreciate the need for rescue, and to know how to help without becoming a second victim.
7. Almost all drowning victims are able to help themselves or are rescued in time. In areas where lifeguards fully operate, less than 1% of all persons rescued need cardiopulmonary resuscitation (CPR).

ANNOTATED REFERENCES

Szpilman D, Handley AJ, Bierens JJ, Quan L, Vasconcellos R. Drowning. In: Field JM. The textbook of emergency cardiovascular care and CPR. Philadelphia: Lippincott Williams & Wilkins; 2009, p. 477–489. Co-sponsored by AHA & ACEP.

A very good review on drowning, with information on epidemiology, prevention, rescue, and treatment, with special attention on the drowning chain of survival.

Field JM. Drowning. In ACLS resource text for instructors and experienced providers. Dallas: American Heart Association Inc.; 2008, p. 301–317.

Presents information on advanced cardiac life support and excellent flow charts to be followed as protocols.

Bierens JJ. Handbook on drowning: prevention, rescue and treatment. Heidelberg, Germany: Springer-Verlag; 2006.

This is a unique book for those involved in aquatic incidents and more specifically, for those involved with drowning incidents. The most complete edition of drowning content, this book is based on the World Drowning Congress 2002—The Netherlands, with contributions by world experts.

Orlowski JP, Szpilman D. Drowning. Rescue, resuscitation, and reanimation. Pediatr Clin North Am 2001;48:627–646.

A good review article highlighting issues such as prevention, physiopathology, basic life support for drowning, and treatment.

Szpilman D. Near-drowning and drowning classification: a proposal to stratify mortality based on the analysis of 1831 cases. Chest 1997;112(3):660–665.

This retrospective study reviewed 41,279 cases of water rescues to establish classifications for drowning according to severity based on the mortality rate of subgroups.

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;19:1390–1395.

This retrospective study reveals important prognostic indicators, highlighting submersion time as the primary prognostic factor.

Cummins RO, Szpilman D. Submersion. In: Cummins RO, Field JM, Hazinski MF, eds. ACLS—the reference textbook. Vol 1. *ACLS for experienced providers*. Dallas: American Heart Association Inc.; 2003, p. 97–107.

An excellent review that highlights important issues such as in-water resuscitation, cervical trauma, and prognostic indicators in the prehospital setting.

References for this chapter can be found at expertconsult.com.

REFERENCES

1. Global report on drowning: preventing a leading killer [Internet]. Australian Policy Online website: http://apo.org.au/node/42350 2014. Accessed 2014 Dec 6.
2. Szpilman D, Handley AJ, Bierens JJ, Quan L, Vasconcellos R. Drowning. In: Field JM, editor. The textbook of emergency cardiovascular care and CPR. Philadelphia: Lippincott Williams & Wilkins; 2009, p. 477–489.
3. Lu TH, Lunetta P, Walker S. Quality of cause-of-death reporting using ICD-10 drowning codes: a descriptive study of 69 countries. BMC Med Res Methodol 2010;10:30.
4. Szpilman D. Near-drowning and drowning classification: a proposal to stratify mortality based on the analysis of 1831 cases. Chest 1997;112:660–665.
5. Venema AM, Groothoff JW, Bierens JJ. The role of bystanders during rescue and resuscitation of drowning victims. Resuscitation 2010;81:434–439.
6. Murray CJL. Quantifying the burden of disease: the technical basis for disability-adjusted life years. Bull World Health Organ 1994;72:429–445.
7. Mitchell RJ, Williamson AM, Olivier J. Estimates of drowning morbidity and mortality adjusted for exposure to risk. Injury Prevention 2010;16:261–266.
8. Moran K, Quan L, Franklin R, Bennett E. Where the evidence and expert opinion meet: a review of open-water recreational safety messages. Int J Aquat Res Educ 2011;5:251–270.
9. Orlowski JP, Szpilman D. Drowning—rescue, resuscitation, and reanimation. In: Pediatric critical care: a new millennium. W. B. Saunders Company Pediatric Clinics of North America 2001;V48:627–646.
10. Szpilman D, Webber J, Quan L, Bierens JJ, Morizot-Leite L, Langendorfer SJ, Beerman S, Løfgren B. Creating a drowning chain of survival. Resuscitation 2014;85:1149–1152.
11. Van Beeck EF, Branche CM, Szpilman D, Modell JH, Bierens JJ. A new definition of drowning: towards documentation and prevention of a global public health problem. Bull World Health Organization 2005;83:853–856.
12. Idris AH, Berg RA, Bierens JJ, Bossaert L, Branche CM, Gabrielli A, et al. Recommended guidelines for uniform reporting of data from drowning: the "Utstein style." American Heart Association. Circulation 2003;108:2565–2574.
13. Szpilman D, Elmann J, Cruz-Filho FES. Dry-drowning—fact or myth?; World Congress on Drowning, Netherlands 2002, Book of Abstracts, ISBN:90-6788-280-01, Poster presentation, pg 176.
14. Lunetta P, Modell JH, Sajantila A. What is the incidence and significance of "dry-lungs" in bodies found in water? Am J Forensic Med Pathol 2004;25:291–301.
15. Orlowski JP, Abulleil MM, Phillips JM. The hemodynamic and cardiovascular effects of near-drowning in hypotonic, isotonic, or hypertonic solutions. Ann Emerg Med 1989;18:1044–1049.
16. 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;2:7–12.
17. Tipton MJ, Golden FStC. A proposed decision-making guide for the search, rescue and resuscitation of submersion (head under) victims based on expert opinion. Resuscitation 2011;82:819–884.
18. Modell JH, Moya F, Newby EJ, Ruiz BC, Showers AV. The effects of fluid volume in seawater drowning. Ann Intern Med 1967;67:68–80.
19. Quan L, Pilkey D, Gomez A, Bennett E. Analysis of paediatric drowning deaths in Washington State using the child death review for surveillance: what the CDR tells us and doesn't tell us about lethal drowning injury. Inj Prev 2011;17:28–33.
20. Deleted in review.
21. Langendorfer SJ. Applying a development perspective to aquatics and swimming. In: Kjendlie PL, Stallman RK, Cabri J, editors. Biomechanics and medicine in swimming XI; 2010, p. 20–22.
22. Deleted in review.
23. Deleted in review.
24. Turgut A, Turgut B. A study on rescuer drowning and multiple drowning incidents. J Safety Res 2012;43:129–132.
25. Szpilman D, Soares M. In-water resuscitation—is it worthwhile? Resuscitation 2004;63:25–31.
26. Watson RS, Cummings P, Quan L, Bratton S, Weiss NS. Cervical spine injuries among submersion victims. J Trauma 2001;51:658–662.
27. Szpilman D, Brewster C, Cruz-Filho FES. Aquatic cervical spine injury—how often do we have to worry? World Congress on Drowning, Netherlands 2002, Oral Presentation.
28. Szpilman D. Aquatic cervical and head trauma: nobody told me it could be a jump in the darkness! World Conference on Drowning Prevention. Danang, Vietnam, 2011, Book of Abstracts, ISBN: 978-0-909689-33-9, p. 153.
29. Wernicke P, Szpilman D. Immobilization and extraction of spinal injuries; Section 6, Resuscitation. In: Handbook on drowning: prevention, rescue, and treatment. Bierens JJ, ed. Berlin: Springer-Verlag; 2014, p. 621–628.
30. Soar J, Perkins GD, Abbasc G, Alfonzo A, Barelli A, Bierens JJ, 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;81:1400–1433.
31. Szpilman D, Handley A. Positioning the drowning victim. In Bierens JJ, ed. Handbook on drowning: prevention, rescue, and treatment. Berlin: Springer-Verlag; 2006, p. 336–341.
32. Vanden Hoek TL, Morrison LJ, Shuster M, Donnino M, Sinz E, Lavonas EJ, et al. Part 12: Cardiac arrest in special situations: drowning. 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation 2010;122:S847–S848.
33. Kitamura T, Iwami T, Kawamura T, Nagao K, Tanaka H, Nadkarni VM, Berg RA, Hiraide A. Conventional and chest-compression-only cardiopulmonary resuscitation by bystanders for children who have out-of-hospital cardiac arrests: a prospective, nationwide, population-based cohort study. Lancet 2010;375:1347–1354.
34. Deleted in review.
35. Baker PA, Webber JB. Failure to ventilate with supraglottic airways after drowning. Anaesth Intensive Care 2011;39:675–677.
36. Manolios N, Mackie I. Drowning and near-drowning on Australian beaches patrolled by life-savers: a 10-year study, 1973-1983. Med J Aust 1988;148:165–167, 170–171.
37. Beerman S, Lofgren B. Automated external defibrillator in the aquatic environment. In Bierens JJ, ed. Handbook on drowning: prevention, rescue, and treatment. Berlin: Springer-Verlag; 2006, p. 331–336.
38. Szpilman D, Elmann J, Cruz-Filho RES. Drowning classification: a revalidation study based on the analysis of 930 cases over 10 years. World Congress on Drowning, Amsterdam 2002, Book of Abstracts, pg 66.
39. Orlowski JP. Drowning, near-drowning, and ice water submersion. Pediatr Clin North Am 1987;34:92.
40. Berkel M, Bierens JJ, Lie RL, de Rooy TP, Kool LJ, van de Velde EA, et al. Pulmonary oedema, pneumonia and mortality in submersions victims: a retrospective study in 125 patients. Intensive Care Med 1996;22:101–107.
41. Deleted in review.
42. Wood C. Towards evidence based emergency medicine: best BETs from the Manchester Royal Infirmary. BET, 1, prophylactic antibiotics in near-drowning. Emerg Med J 2010;27:393–394.
43. Abdul Aziz KA, Meduoye A. Is pH-stat or alpha-stat the best technique to follow in patients undergoing deep hypothermic circulatory arrest? Interactive Cardiovascular and Thoracic Surgery 2010;10:271–282.
44. The NICE-SUGAR Study Investigators. Intensive versus conventional glucose control in critically ill patients. N Engl J Med 2009;360:1283–1297.
45. Tipton MJ, Golden FStC. A proposed decision-making guide for the search, rescue and resuscitation of submersion (head under) victims based on expert opinion. Resuscitation 2011;82:819–824.
46. Wang CH, Chou CC, Ko WJ, Lee YC. Rescue a drowning patient by prolonged extra corporeal membrane oxygenation support for 117 days. Am J Emerg Med 2010; 28:750e5–750e7.
47. 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;80:379–381.
48. Polderman KH. Application of therapeutic hypothermia in the ICU: opportunities and pitfalls of a promising treatment modality. Part 1: indications and evidence. Intens Care Med 2004;30:556–575.
49. Takano Y, Hirosako S, Yamaguchi T, Saita N, Suga M, Kukita I, et al. Nitric oxide inhalation as an effective therapy for acute respiratory distress syndrome due to near-drowning: a case report. Nihon Kokyuki Gakkai Zasshi 1999;37:997–1002.
50. Warner D, Knape J. Recommendations and consensus brain resuscitation in the drowning victim. In: Bierens JJ, ed. Handbook on drowning: prevention, rescue and treatment. Berlin: SpringerVerlag; 2006, p. 436–439.
51. Szpilman D. A case report of 22 minutes submersion in warm water without sequelae. Resuscitation. In: Bierens JJ, ed. Handbook on drowning: prevention, rescue and treatment. Berlin: Springer-Verlag; 2005, p. 375–376.
52. Deleted in review.
53. Deleted in review.
54. Deleted in review.