REVIEW ARTICLE

CURRENT CONCEPTS

Drowning

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According to the World Health Organization (WHO), 0.7% of all deaths worldwide — or more than 500,000 deaths each year[1] — are due to unintentional drowning.[2] Since some cases of fatal drowning are not classified as such according to the codes of the *International Classification of Disease*, this number underestimates the real figures, even for high-income countries,[3] and does not include drownings that occur as a result of floods, tsunamis, and boating accidents.

Drowning is a leading cause of death worldwide among boys 5 to 14 years of age.[2] 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,[4] and in some countries, such as Thailand, the death rate among 2-year-old children is 107 per 100,000.[5] In many countries in Africa and in Central America, the incidence of drowning is 10 to 20 times as high as the incidence in the United States. Key risk factors for drowning are male sex,[4] age of less than 14 years,[6] alcohol use,[7] low income,[1] poor education,[5] rural residency,[5] aquatic exposure,[6,7] risky behavior,[6,7] and lack of supervision.[6] For people with epilepsy, the risk of drowning is 15 to 19 times as high as the risk for those who do not have epilepsy.[8] Exposure-adjusted, person-time estimates for drowning are 200 times as high as such estimates for deaths from traffic accidents.[9] Coastal drownings are estimated to cost more than $273 million per year in the United States[10] and more than $228 million per year (in U.S. dollars) in Brazil.[11] For every person who dies from drowning, another four persons receive care in the emergency department for nonfatal drowning.[12]

DEFINITION AND TERMINOLOGY

According to the new definition adopted by the WHO in 2002, "Drowning is the process of experiencing respiratory impairment from submersion/immersion in liquid."[13] The drowning process begins with respiratory impairment as the person's airway goes below the surface of the liquid (submersion) or water splashes over the face (immersion). If the person is rescued at any time, the process of drowning is interrupted, which is termed a nonfatal drowning. If the person dies at any time as a result of drowning, this is termed 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 be avoided.[13] A uniform way to report data after a drowning event in order to allow comparison among different medical centers is to adopt the Utstein template for categorization of drowning (for details, see the Supplementary Appendix, available with the full text of this article at NEJM.org).[14,15]

PATHOPHYSIOLOGY OF DROWNING

When a drowning person can no longer keep his or her airway clear, water entering the mouth is voluntarily spat out or swallowed. The next conscious response is to hold one's breath, but this lasts for no more than about a minute.[16] When the inspiratory drive is too high to resist, some amount of water is aspirated into the airways, and coughing occurs as a reflex response. Sometimes laryngospasm occurs, but in such cases, it is rapidly terminated by the onset of brain hypoxia. If the person is not rescued, aspiration of water continues, and hypoxemia quickly leads to loss of consciousness and apnea. The sequence of cardiac-rhythm deterioration is usually tachycardia followed by bradycardia, pulseless electrical activity, and, finally, asystole.[17,18] The whole drowning process, from submersion or immersion to cardiac arrest, usually occurs in seconds to a few minutes, but in unusual situations, such as hypothermia or drowning in ice water, this process can last for an hour.[19]

If the person is rescued alive, the clinical picture is determined predominantly by the amount of water that has been aspirated and its effects. Water in the alveoli causes surfactant dysfunction and washout. Aspiration of salt water and aspiration of fresh water cause similar degrees of injury,[17] although with differences in osmotic gradients. In either situation, the effect of the osmotic gradient on the very delicate alveolar–capillary membrane disrupts the integrity of the membrane, increases its permeability, and exacerbates fluid, plasma, and electrolyte shifts.[17] The clinical picture of the damage caused to the alveolar–capillary membrane is a massive, often bloodstained, pulmonary edema that decreases the exchange of oxygen and carbon dioxide.[17,20,21] The combined effects of fluids in the lungs, loss of surfactant, and increased permeability of the alveolar–capillary membrane result in decreased lung compliance, increased regions of very low or zero ventilation to perfusion in the lungs, atelectasis, and bronchospasm.[17]

If cardiopulmonary resuscitation (CPR) is required, the risk of neurologic damage is similar to that in other instances of cardiac arrest. However, hypothermia associated with drowning can provide a protective mechanism that allows persons to survive prolonged submersion episodes. Hypothermia can reduce the consumption of oxygen in the brain, delaying cellular anoxia and ATP depletion. Hypothermia reduces the electrical and metabolic activity of the brain in a temperature-dependent fashion. The rate of cerebral oxygen consumption is reduced by approximately 5% for each reduction of 1°C in temperature within the range of 37°C to 20°C.[22]

RESCUE AND IN-WATER RESUSCITATION

Many persons who are drowning are able to help themselves or are rescued in time by bystanders or professional rescuers. In areas where lifeguards operate, less than 6% of all rescued persons need medical attention[4] and just 0.5% need CPR.[21] In one report of rescues by bystanders, almost 30% of persons rescued from drowning required CPR.[23] Untrained rescuers must also avoid drowning[23] and, if at all possible, should provide help from out of the water. Safe rescue techniques include reaching to the drowning person with an object such as a pole, towel, or tree branch or throwing a buoyant object. These quick, safe responses are often neglected and should be taught as part of water safety.

It is essential to call for emergency medical services and to undertake rescue and resuscitation immediately.[23] If conscious, the person should be brought to land, and basic life support should be started as soon as possible.[22] For a person who is unconscious, in-water resuscitation may increase the likelihood of a favorable outcome by a factor of more than three, as compared with taking the time to bring the person to land.[24] However, in-water resuscitation is possible only when attempted by a highly trained rescuer, and it consists of ventilation alone. Attempts at chest compression are futile as long as the rescuer and drowning person are in deep water, so assessment for a pulse does not serve any purpose.[24] Drowning persons with only respiratory arrest usually respond after a few rescue breaths. If there is no response, the person should be assumed to be in cardiac arrest and be taken as quickly as possible to dry land, where effective CPR can be initiated.[24]

Injuries to the cervical spine occur in less than 0.5% of persons who are drowning, and immobilization of the spine in the water is indicated only in cases in which head or neck injury is strongly suspected (e.g., accidents involving diving, waterskiing, surfing, or watercraft).[25] When rescuing a person from the water, rescuers should try to maintain the person in a vertical position while keeping the airway open, which helps to prevent vomiting and further aspiration of water and stomach contents.[26]

Figure 1 (facing page). Treatment of Persons Who Have Drowned, with Classification System.

This classification system can help to stratify risk and guide interventions. The likelihood of survivability was calculated on the basis of time from the site of drowning until hospital discharge. Information is based on a retrospective review of 41,279 rescues recorded by lifeguards, of which 94% (38,975 cases) were just rescues (no water aspiration); less than 6% of these cases (1831) involved the receipt of medical attention, but 1% (473) were not reported with sufficient information to classify the grade of presentation.[21,34] Of the 1831 cases that received medical attention at the Drowning Resuscitation Center in Rio de Janeiro during the period from 1972 through 1991, 65% were classified as a grade 1 presentation (1189 cases), 18% as grade 2 (338), 3% as grade 3 (58), 2% as grade 4 (36), 1% as grade 5 (25), and 10% as grade 6 (185).[4] ABC denotes airway–breathing–circulation, and CPR cardiopulmonary resuscitation.

INITIAL RESUSCITATION ON LAND

Once on land, the person who has drowned should be placed in a supine position, with the trunk and head at the same level (usually parallel to the shoreline), and the standard checks for responsiveness and breathing should be carried out.[24] If the person is unconscious but breathing, the recovery position (lateral decubitus) should be used.[26] If the person is not breathing, rescue ventilation is essential. Unlike primary cardiac arrest, drowning can produce a gasping pattern or apnea while the heart is still beating, and the person may need only ventilation.[21,27-29]

Cardiac arrest from drowning is due primarily to lack of oxygen.[28-30] For this reason, it is important that CPR follow the traditional airway–breathing–circulation (ABC) sequence, rather than the circulation–airway–breathing (CAB) sequence, starting with five initial rescue breaths, followed by 30 chest compressions, and continuing with two rescue breaths and 30 compressions until signs of life reappear, the rescuer becomes exhausted, or advanced life support becomes available. In cases of drowning, the European Resuscitation Council recommends five initial rescue breaths instead of two because the initial ventilations can be more difficult to achieve, since water in the airways can interfere with effective alveolar expansion.[29,31] CPR with chest compression only is not advised in persons who have drowned.[28-30]

The most frequent complication during a resuscitation attempt is the regurgitation of stomach contents, which occurs in more than 65% of persons who require rescue breathing alone and in 86% of those who require CPR.[32] The presence of vomitus in the airway often results in further aspiration injury and impairment of oxygenation.[24] Active efforts to expel water from the airway (by means of abdominal thrusts or placing the person head down) should be avoided because they delay the initiation of ventilation and greatly increase the risk of vomiting, with a significant increase in mortality.[24,26] The resuscitation of drowning persons often takes place under difficult and quite varied circumstances. There may be problems in bringing the person to dry land, and the delay until the arrival of emergency medical services may be considerable. On the other hand, drowning persons are generally young, and the rate of successful resuscitation is higher among young persons than among older persons, often because hypothermia affects young people more quickly than adults, so the chances of successful resuscitation may increase.[18,23,33]

ADVANCED PREHOSPITAL CARE

In addition to providing immediate basic life support, it is important to alert advanced-life-support teams as soon as possible. Because of the wide variety of clinical presentations of drowning, a classification system of six grades, with higher numbers indicating more severe impairment, can help to stratify risk and guide interventions (Fig. 1).[21,34]

A person with pulmonary damage may initially be able to maintain adequate oxygenation through an abnormally high respiratory rate and can be treated by the administration of oxygen by face mask at a rate of 15 liters of oxygen per minute. Early intubation and mechanical ventilation are indicated when the person shows signs of deterioration or fatigue (grade 3 or 4).[21] Once intubated, most persons can be oxygenated and ventilated effectively. Although copious pulmonary-edema

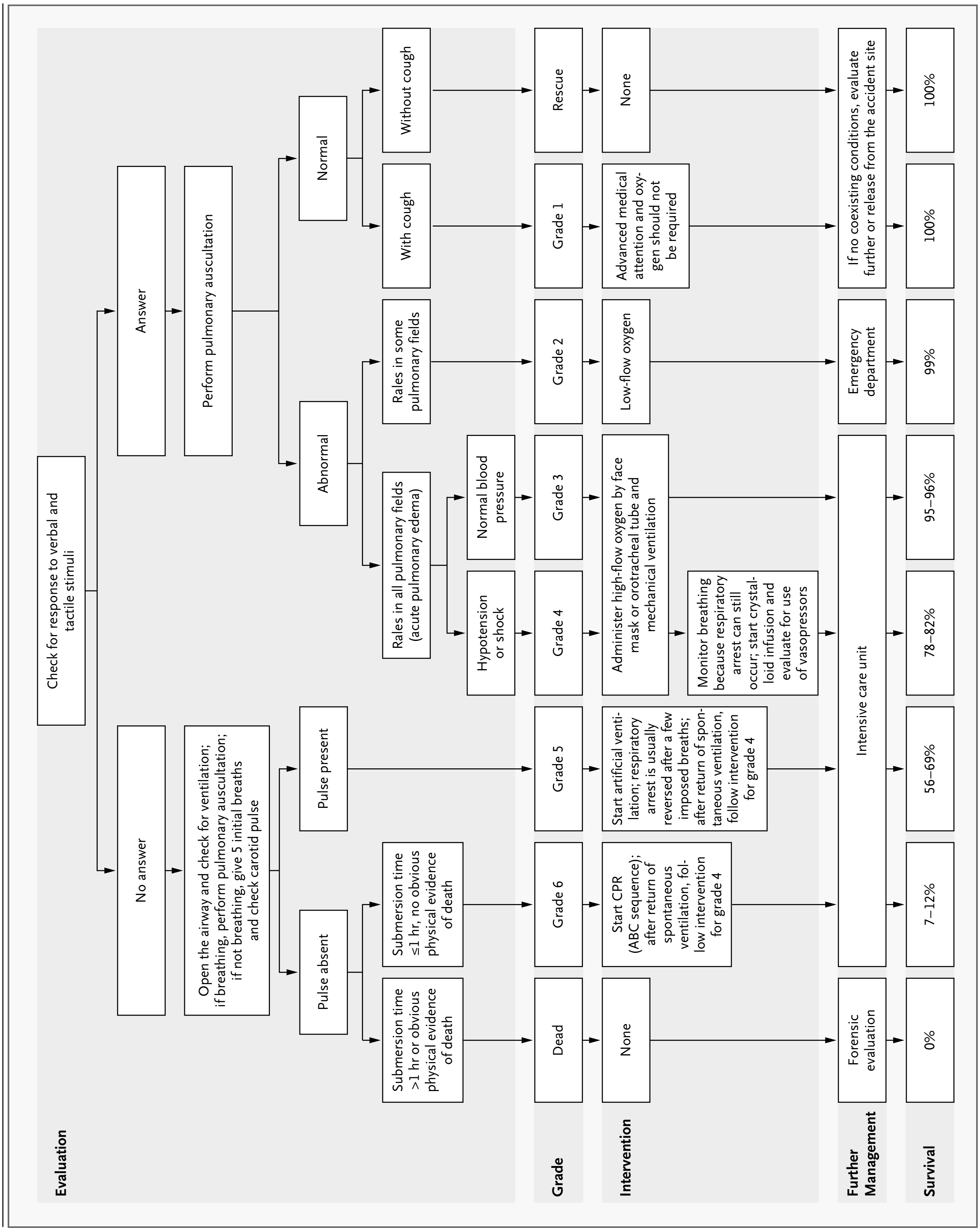
Evaluation
Check for response to verbal and tactile stimuli
No answer
Answer
Open the airway and check for ventilation; if breathing, perform pulmonary auscultation; if not breathing, give 5 initial breaths and check carotid pulse
Perform pulmonary auscultation
Pulse absent
Pulse present
Abnormal
Normal
Submersion time >1 hr or obvious physical evidence of death
Submersion time ≤1 hr, no obvious physical evidence of death
Rales in all pulmonary fields (acute pulmonary edema)
Rales in some pulmonary fields
With cough
Without cough
Hypotension or shock
Normal blood pressure
Grade
Dead
Grade 6
Grade 5
Grade 4
Grade 3
Grade 2
Grade 1
Rescue
Intervention
None
Start CPR (ABC sequence); after return of spontaneous ventilation, follow intervention for grade 4
Start artificial ventilation; respiratory arrest is usually reversed after a few imposed breaths; after return of spontaneous ventilation, follow intervention for grade 4
Administer high-flow oxygen by face mask or orotracheal tube and mechanical ventilation
Monitor breathing because respiratory arrest can still occur; start crystalloid infusion and evaluate for use of vasopressors
Low-flow oxygen
Advanced medical attention and oxygen should not be required
None
Further Management
Forensic evaluation
Intensive care unit
Emergency department
If no coexisting conditions, evaluate further or release from the accident site
Survival
0%
7–12%
56–69%
78–82%
95–96%
99%
100%
100%

Table 1. Use of CPR in Cases of Drowning.*

CPR	Recommendation
When to initiate	Initiate ventilation in persons with respiratory distress or respiratory arrest in order to prevent cardiac arrest[21,29]
	Initiate CPR in persons who have been submerged for <60 min and who do not have obvious physical evidence of death (rigor mortis, body decomposition, or livor mortis)[21,29]
When to discontinue	Continue basic life support unless signs of life reappear, rescuers are exhausted, or advanced-life-support team takes over
	Continue advanced life support until patient has been rewarmed (if hypothermic) and asystole has persisted for >20 min[28]

* CPR denotes cardiopulmonary resuscitation.

fluid may appear in the endotracheal tube, suctioning can disturb oxygenation and should be balanced against the need to ventilate and oxygenate.[35,36] Providers of prehospital care should ensure that there is adequate oxygenation to maintain arterial saturation between 92% and 96%, while also ensuring adequate chest rise during ventilation.[37] Ventilation with positive end-expiratory pressure should be initiated as soon as possible to increase oxygenation.[35]

Peripheral venous access is the preferred route for drug administration in the prehospital setting. Intraosseous access is an alternative route. Endotracheal administration of drugs is not recommended.[28] If hypotension is not corrected by oxygenation, a rapid crystalloid infusion should be administered, regardless of whether salt water or fresh water has been inhaled.[17]

The presenting rhythm in cases of cardiac arrest after drowning (grade 6) is usually asystole or pulseless electrical activity. Ventricular fibrillation is rarely reported but may occur if there is a history of coronary artery disease, if there has been use of norepinephrine or epinephrine (which may increase myocardial irritability), or in the presence of severe hypothermia.[18] During CPR, if ventilation and chest compression do not result in cardiac activity, a series of intravenous doses of norepinephrine or epinephrine, at an individual dose of 1 mg (or 0.01 mg per kilogram of body weight) can be considered. Because of the mechanisms of cardiac arrest due to hypoxia and the effects of hypothermia, a higher subsequent dose, although controversal,[38] may be considered if the initial doses are ineffective.

The cost-effectiveness of providing an automated external defibrillator (AED) at sites of aquatic activity has been debated. The predominant cardiac-arrest rhythm in drowning is asystole.[39] Of course, cardiac arrests at aquatic sites occur from causes other than drowning, and the availability of an AED may be lifesaving.[39] Table 1 summarizes the recommendations on when to begin CPR and how long it should be maintained in cases of drowning.

CARE IN THE EMERGENCY DEPARTMENT

The majority of drowning persons aspirate only small amounts of water, if any, and will recover spontaneously. Less than 6% of all persons who are rescued by lifeguards need medical attention in a hospital.[21]

Once the airway has been secured, oxygenation has been improved, the circulation has been stabilized, and a gastric tube has been inserted, thermal insulation of the patient should be instituted. This is followed by physical examination, chest radiography, and measurement of arterial blood gases. Metabolic acidosis occurs in the majority of patients and is usually corrected by the patient's spontaneous effort to increase minute ventilation or by setting a higher minute ventilation (30 to 35 liters per minute) or a higher peak inspiratory pressure (35 cm of water) on the mechanical ventilator.[20] Routine use of sodium bicarbonate is not recommended. The recorded history of events surrounding the drowning incident should include information on the rescue and resuscitation activities and any current or previous illness.[15] Drowning is sometimes precipitated by an injury or medical condition (e.g., trauma, seizure, or cardiac arrhythmia), and such conditions affect treatment decisions.[21,40]

If the person remains unresponsive without an obvious cause, a toxicologic investigation and computed tomography of the head and neck should be considered.[41] Measurements of electrolytes, blood urea nitrogen, creatinine, and hematocrit are rarely helpful; abnormalities are unusual,[20] and correction of electrolyte imbalance is rarely needed.[42]

Persons who have good arterial oxygenation without adjuvant therapy and who have no other associated morbidity can be safely discharged. Hospitalization is recommended for all patients with a presentation of grade 2 to 6. For most patients with a grade 2 presentation, noninvasive oxygen administration results in normalization of clinical status within 6 to 8 hours, and they can then be sent home.[21] Patients whose clinical status deteriorates are admitted to an intermediate care unit for prolonged observation. Patients with a presentation of grade 3 to 6, who usually need intubation and mechanical ventilation, are admitted to an intensive care unit (ICU).[21]

TREATMENT IN THE ICU

RESPIRATORY SYSTEM

In the ICU, the current treatment of persons who have been rescued from drowning resembles that of patients with the acute respiratory distress syndrome (ARDS). Guidelines for ventilation in ARDS should be followed. However, since the pulmonary lesion is caused by a temporary and local injury, patients with pulmonary distress due to a drowning incident tend to recover much faster than patients with ARDS, and late pulmonary sequelae are uncommon.[35] It is usually best not to initiate weaning from mechanical ventilation for at least 24 hours, even when gas exchange appears to be adequate (ratio of the partial pressure of arterial oxygen to the fraction of inspired oxygen, >250). The local pulmonary injury may not have resolved sufficiently, and pulmonary edema may recur, necessitating reintubation and leading to a prolonged hospital stay and further morbidity.[43] There is very little evidence concerning the value of glucocorticoid therapy for reducing pulmonary injury. It may have a beneficial effect on bronchospasm but should be considered only after a trial of bronchodilators has failed.[44]

Pneumonia is often misdiagnosed initially because of the early radiographic appearance of water in the lungs. In a series of hospitalized cases, only 12% of persons rescued from drowning had pneumonia and needed treatment with antibiotic agents.[45] Prophylactically administered antibiotics tend to select more resistant and aggressive organisms.[46] It is best to monitor patients daily for definite fever, sustained leukocytosis, persistent or new pulmonary infiltrates, and leukocyte response in the tracheal aspirate, with culture and sensitivity testing of sputum specimens obtained daily from the aspirate. In addition, bronchoscopy may be performed to monitor selected patients for pulmonary infection and, on rare occasions, is used for therapeutic clearing of mucus plugs or solid material.[47]

Table 2. Important Facts and Predictors of Outcome in Resuscitation of a Person Who Has Drowned.

Early basic life support and advanced life support improve outcome[21,24,33,54]
During drowning, a reduction of brain temperature by 10°C decreases ATP consumption by approximately 50%, doubling the duration of time that the brain can survive[55]
Duration of submersion and risk of death or severe neurologic impairment after hospital discharge[19,21,24,32]
0–5 min — 10%
6–10 min — 56%
11–25 min — 88%
>25 min — nearly 100%
Signs of brain-stem injury predict death or severe neurologic sequelae[21,24,33,41]
Prognostic factors are important in the counseling of family members and are crucial in informing decisions regarding more aggressive cerebral resuscitation therapies[51]

Early-onset pneumonia can be due to the aspiration of polluted water, endogenous flora, or gastric contents. Aspiration of swimming-pool water rarely results in pneumonia.[45] The risk of pneumonia increases during prolonged mechanical ventilation and can be detected by the third or fourth day of hospitalization, when pulmonary edema has nearly resolved.[45] Pneumonia is often related to nosocomial pathogens. Once a diagnosis is made, empirical therapy with broad-spectrum antibiotics, covering the most predictable gram-negative and gram-positive pathogens, should be started,[45] and definitive therapy should be substituted once the results of culture and sensitivity testing are available. Fungal and anaerobic infections should be considered but can await culture results.

In some patients, pulmonary function deteriorates so dramatically that adequate oxygenation can be maintained only with the use of extracorporeal membrane oxygenation. For these critically ill patients, artificial surfactant,[48] inhaled nitric oxide,[49] and partial liquid ventilation with perfluorocarbons[50] are under investigation; none of these treatments can be recommended now.

CIRCULATORY SYSTEM

In most persons who have been rescued from drowning, the circulation becomes adequate after oxygenation, rapid crystalloid infusion, and restoration of normal body temperature.[17,35] Early cardiac dysfunction can occur in patients with a

Table 3. Guidelines for Prevention of Drowning.*

Keep yourself safe
Learn swimming and water-safety survival skills
Always swim with others
Obey all safety signs and warning flags
Never go in the water after drinking alcohol
Avoid inflatable swimming aids, such as “floaters”; know how and when to use a life jacket
Swim in areas with lifeguards
Know the weather and water conditions before going in the water
Always enter shallow or unfamiliar water feet first
Do not overestimate swimming capability[27]
Know how to stay away from rip currents, which are involved in more than 85% of drowning events at the beach[27]
Keep others safe
Help and encourage others, especially children, to learn swimming and water-safety survival skills
Swim in areas with lifeguards
Set rules for water safety
Always provide close and constant attention to children you are supervising in or near water
Know how and when to use a life jacket, especially for children and weak swimmers
Learn first aid and CPR
Learn safe ways of rescuing others without putting yourself in danger
Obey all safety signs and warning flags
Fence in a pool on four sides and install a self-closing, self-latching gate, measures that reduce the incidence of drowning by 50 to 70%[27]
Provide a warning sign for shallow water in a pool[27]

* The first eight messages in each section are from the International Open Water Drowning Prevention Task Force.[56]

presentation of grade 4 to 6,[17] which adds a cardiogenic component to the noncardiogenic pulmonary edema. No evidence supports the use of a specific fluid therapy, diuretics, or water restriction[27] in persons who have been rescued from drowning in salt water or fresh water.[17] If volume replacement with a crystalloid infusion fails to restore hemodynamic adequacy, echocardiography can help inform decisions about the use of inotropic agents, vasopressors, or both.[27]

NEUROLOGIC SYSTEM

Permanent neurologic damage is the most worrisome outcome in persons who have been resuscitated after a drowning incident. According to the recommendations of a consensus group,[51] persons who are comatose or have neurologic deterioration should undergo intensive assessment and care; the goals are to achieve normal values for glucose, partial pressure of arterial oxygen, and partial pressure of carbon dioxide, with avoidance of any situation that increases brain metabolism. Induced hypothermia with the core temperature maintained between 32°C and 34°C for 24 hours may be neuroprotective.[51]

In some cases, hypothermia reflects a prolonged submersion time and a poor prognosis. In other cases, early hypothermia is an important reason why survival without neurologic damage is possible.[19,29,49] Recent reports on drowning have documented good outcomes with the use of therapeutic induction of hypothermia after resuscitation, despite a predicted poor outcome.[28,52] The paradox in resuscitation after drowning is that a person with hypothermia needs to be warmed initially in order to be effectively resuscitated but then may benefit from induced therapeutic hypothermia after successful resuscitation.

UNUSUAL COMPLICATIONS

A systemic inflammatory response syndrome after resuscitation has been reported in persons who have been rescued from drowning, but this should not be misinterpreted as infection. Sepsis and disseminated intravascular coagulation are possible complications during the first 72 hours after resuscitation.[27] Renal insufficiency or failure is rare but can occur as a result of anoxia, shock, myoglobinuria, or hemoglobinuria.[53] The most important predictors of the outcome after resuscitation are summarized in Table 2.

PREVENTION

Every drowning signals the failure of the most effective intervention — namely, prevention.[56] Table 3 summarizes recreational safety messages that are based on evidence and expert opinion.[56] It is estimated that more than 85% of cases of drowning can be prevented by supervision, swimming instruction, technology, regulation, and public education.[57]

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REFERENCES

1. Peden M, McGee K, Sharma K. The injury chart book: a graphical overview of the global burden of injuries. Geneva: World Health Organization, 2002.
2. Injuries and violence prevention: noncommunicable diseases and mental health: fact sheet on drowning. Geneva: World Health Organization, 2003 (http://www.who.int/violence_injury_prevention/other_injury/drowning/en/index.html).
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. Borse NN, Gilchrist J, Dellinger AM, Rudd RA, Ballesteros MF, Sleet DA. CDC childhood injury report: patterns of unintentional Injuries among 0–19 year olds in the United States, 2000–2006. Atlanta: Centers for Disease Control and Prevention, 2008.
5. Linnan M, Anh LV, Cuong PV, et al. Special series on child injury: child mortality and injury in Asia: survey results and evidence. Florence, Italy: UNICEF Innocenti Research Center, 2007.
6. Modell JH. Prevention of needless deaths from drowning. South Med J 2010;103:650-3.
7. Cummings P, Mueller BA, Quan L. Association between wearing a personal floatation device and death by drowning among recreational boaters: a matched cohort analysis of United States Coast Guard data. Inj Prev 2011;17:156-9.
8. Bell GS, Gaitatzis A, Bell CL, Johnson AL, Sander JW. Drowning in people with epilepsy: how great is the risk? Neurology 2008;71:578-82.
9. Mitchell RJ, Williamson AM, Olivier J. Estimates of drowning morbidity and mortality adjusted for exposure to risk. Inj Prev 2010;16:261-6.
10. Branche CM, Stewart S, eds. Lifeguard effectiveness: a report of the Working Group. Atlanta: Centers for Disease Control and Prevention, 2001.
11. Informações de Saúde: Ministério da Saúde do Brasil. Brasilia: Departamento de Informática do SUS, 2008 (http://www2.datasus.gov.br/DATASUS/index.php?area=02).
12. Web-based Injury Statistics Query and Reporting System (WISQARS). Atlanta: Centers for Disease Control and Prevention, 2009 (http://www.cdc.gov/injury/wisqars).
13. van Beeck EF, Branche CM, Szpilman D, Modell JH, Bierens JJLM. A new definition of drowning: towards documentation and prevention of a global public health problem. Bull World Health Organ 2005;83:853-6.
14. Idris AH, Berg RA, Bierens J, et al. Recommended guidelines for uniform reporting of data from drowning: the "Utstein style." Circulation 2003;108:2565-74.
15. Youn CS, Choi SP, Yim HW. Out-of-hospital cardiac arrest due to drowning: an Utstein Style report of 10 years of experience from St. Mary's Hospital. Resuscitation 2009;80:778-83.
16. Sterba JA, Lundgren CE. Diving bradycardia and breath-holding time in man. Undersea Biomed Res 1985;12:139-50.
17. Orlowski JP, Abulleil MM, Phillips JM. The hemodynamic and cardiovascular effects of near-drowning in hypotonic, isotonic, or hypertonic solutions. Ann Emerg Med 1989;18:1044-9.
18. 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.
19. 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;82:819-24.
20. Modell JH, Graves SA, Ketover A. Clinical course of 91 consecutive near-drowning victims. Chest 1976;70:231-8.
21. Szpilman D. Near-drowning and drowning classification: a proposal to stratify mortality based on the analysis of 1831 cases. Chest 1997;112:660-5.
22. Polderman KH. Application of therapeutic hypothermia in the ICU: opportunities and pitfalls of a promising treatment modality. Part 1: indications and evidence. Intensive Care Med 2004;30:556-75.
23. Venema AM, Groothoff JW, Bierens JJ. The role of bystanders during rescue and resuscitation of drowning victims. Resuscitation 2010;81:434-9.
24. Szpilman D, Soares M. In-water resuscitation — is it worthwhile? Resuscitation 2004;63:25-31.
25. Watson RS, Cummings P, Quan L, Bratton S, Weiss NS. Cervical spine injuries among submersion victims. J Trauma 2001;51:658-62.
26. Szpilman D, Handley A. Positioning the drowning victim. In: Bierens JJLM, ed. Handbook on drowning: prevention, rescue, and treatment. Berlin: Springer-Verlag, 2006:336-41.
27. Orlowski JP, Szpilman D. Drowning: rescue, resuscitation, and reanimation. Pediatr Clin North Am 2001;48:627-46.
28. Vanden Hoek TL, Morrison LJ, Shuster M, et al 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:Suppl 3:S847-S848.
29. Soar J, Perkins GD, Abbasc 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;81:1400-33.
30. International Life Saving Federation Medical Committee. Clarification statement on cardiopulmonary resuscitation for drowning. Leuven, Belgium: International Life Saving Federation, April 3, 2008 (http://www.ilsf.org/sites/ilsf.org/files/filefield/ILS%20Clarification%20Statement%20on%20Cardiopulmonary%20Resuscitation%20-%203%20April%2008.pdf).
31. Baker PA, Webber JB. Failure to ventilate with supraglottic airways after drowning. Anaesth Intensive Care 2011;39:675-7.
32. 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;148:165-71.
33. Claesson A, Svensson L, Silfverstolpe J, Herlitz J. Characteristics and outcome among patients suffering out-of-hospital cardiac arrest due to drowning. Resuscitation 2008;76:381-7.
34. Szpilman D, Elmann J, Cruz-Filho FES. Drowning classification: a revalidation study based on the analysis of 930 cases over 10 years. Presented at the World Congress on Drowning, Amsterdam, June 26–28, 2002. abstract.
35. Gregorakos L, Markou N, Psalida V, et al. Near-drowning: clinical course of lung injury in adults. Lung 2009;187:93-7.
36. Diamond W, MacDonald RD. Submersion and early-onset acute respiratory distress syndrome: a case report. Prehosp Emerg Care 2011;15:288-93.
37. Kochanek PM, Bayir H. Titrating oxygen during and after cardiopulmonary resuscitation. JAMA 2010;303:2190-1.
38. Weiss SJ, Muniz A, Ernst AA, Lippton HL, Nick TG. The effect of prior hyperthermia on the physiological response to norepinephrine. Resuscitation 2000;45:201-7.
39. Beerman S, Lofgren B. Automated external defibrillator in the aquatic environment. In: Bierens JJLM, ed. Handbook on drowning: prevention, rescue, and treatment. Berlin: Springer-Verlag, 2006:331-6.
40. Quan L, Cummings P. Characteristics of drowning by different age groups. Inj Prev 2003;9:163-8.
41. Rafaat KT, Spear RM, Kuelbs C, Parsapour K, Peterson B. Cranial computed tomographic findings in a large group of children with drowning: diagnostic, prognostic, and forensic implications. Pediatr Crit Care Med 2008;9:567-72.
42. Oehmichen M, Hennig R, Meissner C. Near-drowning and clinical laboratory changes. Leg Med (Tokyo) 2008;10:1-5.
43. Eggink WF, Bruining HA. Respiratory distress syndrome caused by near- or secondary drowning and treatment by positive end-expiratory pressure ventilation. Neth J Med 1977;20:162-7.

44. Foex BA, Boyd R. Towards evidence based emergency medicine: best BETs from the Manchester Royal Infirmary: corticosteroids in the management of near-drowning. Emerg Med J 2001;18:465-6.
45. van Berkel M, Bierens JJ, Lie RL, et al. Pulmonary oedema, pneumonia and mortality in submersions victims: a retrospective study in 125 patients. Intensive Care Med 1996;22:101-7.
46. 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;27:393-4.
47. Kapur N, Slater A, McEniery J, Greer ML, Masters IB, Chang AB. Therapeutic bronchoscopy in a child with sand aspiration and respiratory failure from near drowning — case report and literature review. Pediatr Pulmonol 2009;44:1043-7.
48. Cubattoli L, Franchi F, Coratti G. Surfactant therapy for acute respiratory failure after drowning: two children victim of cardiac arrest. Resuscitation 2009;80:1088-9.
49. Takano Y, Hirosako S, Yamaguchi T, 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. (In Japanese.)
50. Gauger PG, Pranikoff T, Schreiner RJ, Moler FW, Hirschl RB. Initial experience with partial liquid ventilation in pediatric patients with the acute respiratory distress syndrome. Crit Care Med 1996;24:16-22.
51. Warner D, Knape J. Recommendations and consensus brain resuscitation in the drowning victim. In Bierens JJLM, ed. Handbook on drowning: prevention, rescue, and treatment. Berlin: Springer-Verlag, 2006:436-9.
52. 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;80:379-81.
53. Spicer ST, Quinn D, Nyi Nyi NN, Nankivell BJ, Hayes JM, Savdie E. Acute renal impairment after immersion and near drowning. J Am Soc Nephrol 1999;10:382-6.
54. 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;75:42-52.
55. Gilbert M, Busund R, Skagseth A, Nilsen PÅ, Solbø JP. Resuscitation from accidental hypothermia of 13.7°C with cardiac arrest. Lancet 2000;355:375-6.
56. 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 Aquatic Res Educ 2011;5:251-70.
57. Quan L, Bennett E, Branche CM. Interventions to prevent drowning. In: Doll LS, Bonzo SE, Sleet DA, et al., eds. Handbook of injury and violence prevention. New York: Springer, 2007:81-96.