Drowning and immersion injury

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Learning objectives

After reading this article you should be able to:
- outline the epidemiology and pathophysiology of drowning
- define the management priorities for the drowning victim who reaches hospital
- list the clinical features associated with poor neurological outcome in the drowning victim

Abstract

'Drowning is a process resulting in primary respiratory impairment from submersion/immersion in a liquid medium. The victim may live or die after this process, but whatever the outcome, he or she has been involved in a drowning incident'. There are no specific interventions that have been proven to improve outcomes in drowning victims and thus prevention of drowning is the priority. Underlying medical conditions (whether previously diagnosed or not) must be considered as potentially having contributed to the drowning incident — and may have implications for both the victim and their relatives. Pathophysiological events in the process of drowning are secondary to hypoxaemia that results from the submersion/immersion insult. The major determinant of outcome after drowning is the degree of neurological insult and subsequent recovery. Management priorities in the drowning victim revolve around restoration of oxygenation, circulation and thermoregulation. Compression-only cardiopulmonary resuscitation is not recommended in drowning victims. Hypothermia is common and may limit the efficacy of resuscitative attempts when severe. Therapeutic hypothermia can be considered in the treatment of unconscious survivors of drowning. Patients who are unconscious on admission to hospital have a guarded prognosis.

Keywords Drowning; hypothermia; hypoxaemia; hypoxia; immersion; resuscitation

Epidemiology

In the UK, USA and Australia unintentional drowning is responsible for 0.7–1.14 deaths per 100,000 per year and up to four times as many non-fatal events requiring hospital treatment. The highest incidence is in children less than 5 years old, with a second peak in late adolescence. Males are two to four times more likely to die from drowning than females. Globally it is estimated that 450,000 people drown annually; 97% of drownings occur in low- and middle-income countries.[1,2]

Infants often drown in bathtubs, and non-accidental injury must be considered. Young children commonly drown in swimming pools, while older children and adults tend to drown in rivers, lakes or the ocean during recreational activities such as boating or diving.

Risk factors for drowning include younger age (0–4 years), inability to swim, a lack of pool fencing and inadequate supervision. Conditions increasing the risk of drowning in open water include currents, rips, waves and cold water temperatures. Intoxication with alcohol or drugs contributes to at least 10–30% of drownings particularly in older age groups. Tourists have a higher risk of drowning than locals. Prevention is the best way to reduce the burden of drowning, as there are few effective treatments (Box 2).

Medical conditions associated with an increased risk of drowning include epilepsy, arrhythmias including long QT syndrome (LQTS), cardiomyopathies, coronary artery disease,

Definition

'Drowning is a process resulting in primary respiratory impairment from submersion/immersion in a liquid medium. .... The victim may live or die after this process, but whatever the outcome, he or she has been involved in a drowning incident'.

Previously used descriptions including near-drowning, wet and dry drowning and secondary drowning have become potentially confusing as resuscitation has improved and understanding of the pathophysiology has evolved. These terms are no longer recommended.[3]

Box 1

Prevention

Prevention is the best way to reduce the burden of drowning, as there are few effective treatments. It is estimated that up to 80% of drownings are preventable.

Legislation and education are targeted at:
- Mandatory self-closing and locking pool fencing
- Constant supervision of children in the water
- Reducing drug and alcohol consumption around water
- Wearing lifejackets in boats
- Learning to swim
- Swimming in areas patrolled by lifeguards
- Not swimming alone
- Learning cardiopulmonary resuscitation[4]

Box 2

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cerebrovascular disease, diabetes mellitus, and depression. There is an increasing awareness of first presentation of arrhythmias as a cause of unexplained drowning – with implications for screening of relevant family members in the context of syndromes such as LQT and catecholaminergic polymorphic ventricular tachycardia (CPVT).[5]

Pathophysiology[2–7]

The process of drowning begins with the airway under water, leading to breath-holding, panic, swallowing of water, aspiration and laryngospasm. Hypoxia and hypercapnia develop and unconsciousness ensues. Eventually the larynx relaxes, and fluid is aspirated into the lungs resulting in worsening hypoxia and a mixed metabolic and respiratory acidosis. Survivors probably aspirate less than 3–4 ml/kg fluid, which may be contaminated with sand, mud, vomit or other debris. It was previously thought that some victims had persistent laryngospasm resulting in 'dry drowning', but it is now considered more likely that these patients died from an alternative cause prior to submersion (e.g. primary arrhythmia).

Cardiovascular: during drowning there is initially hypertension and tachycardia with activation of the sympathetic nervous system. However, worsening hypoxia, acidosis and hypothermia lead to bradycardia, pulmonary hypertension and decreased cardiac output. Atrial fibrillation and other arrhythmias may occur, ultimately progressing to asystole. In both survivors and non-survivors of drowning consideration should be given to an underlying primary arrhythmia causing the drowning incident.

Respiratory: Acute lung injury (ALI, see article on Acute Lung Injury in *Anaesthesia & Intensive Care Medicine* 2010; **11** (11):487–9) occurs in up to 70% of symptomatic survivors of drowning. Several mechanisms are responsible for the development of alveolar oedema, progressing in severe cases to the acute respiratory distress syndrome (ARDS). These include the aspirated fluid itself, increased capillary permeability, negative pressure and neurogenic pulmonary oedema. Surfactant washout and dysfunction results in atelectasis, and the combined effect is decreased lung compliance, ventilation–perfusion mismatch and intrapulmonary shunting.

Neurological: hypoxic brain injury is the leading cause of morbidity and mortality in drowning and begins within 5 minutes of inadequate cerebral oxygenation. The clinical spectrum ranges from confusion and disorientation to coma, seizures and death.

Hypothermia: drowning is often complicated by hypothermia, which reflects the duration and severity of the incident. Uncontrolled hypothermia and the cold shock response cause hyperventilation, tachycardia, shivering and activation of the sympathetic nervous system with increased metabolic demand. Only rarely is uncontrolled hypothermia thought to be protective, observed most dramatically in case reports of children surviving prolonged submersion in very cold (<10 °C) water. In this setting the 'diving reflex' – cold water stimulation of the ophthalmic division of the trigeminal nerve resulting in apnoea, bradycardia and profound systemic vasoconstriction – results in preferential perfusion of the heart and brain and may be protective.

Fluid and electrolytes: post-mortem studies and dog experiments suggested that in fresh water drowning, water moves from the alveoli into capillaries, causing haemodilution and hyponatraemia. Conversely, with drowning in seawater, water moves from plasma into the alveoli, exacerbating the pulmonary oedema, and causing hypernatraemia and hypovolaemia. However, in humans who survive drowning, there is no clinically significant difference in volume status, electrolytes or lung function between patients drowning in fresh or salt water. The volume of fluid aspirated is probably insufficient to cause significant volume or electrolyte effects.

Infective complications: aspirated fluid may be contaminated with a variety of microorganisms, leading to infection in up to 50% of drownings. Aerobic Gram-positive organisms such as *Streptococcus* species may be aspirated from the oropharynx. Aerobic Gram-negative organisms including *Pseudomonas*, *Aeromonas* and *Burkholderia pseudomallei* may contaminate fresh water, as may leptospirosis. Fungal infections including delayed CNS infections from *Aspergillus* and *Pseudallescheria boydii* may complicate drowning, especially in immunocompromized patients.

Management[2–7]

Rapid rescue from the water and basic life support at the scene are essential to survival. Cardiac arrest and neurological damage in drowning are due to hypoxia. The priorities in resuscitation are restoring oxygenation, ventilation and perfusion. Rescue breaths and ventilation remain the first step in the resuscitation of drowning victims in the 2010 Advanced Life Support Guidelines. If the patient is in cardiac arrest then cardiopulmonary resuscitation (CPR) should be performed, but 'compression-only CPR' is not appropriate in drowning victims. The risk of cervical spine injury is low,[8] and cervical spine protection is only required where the history or examination is suggestive of severe trauma.

Emergency department treatment remains focussed on maintaining oxygenation and cardiac output. Hypothermia is common in drowning victims and active rewarming should be instituted to facilitate resuscitation in severely hypothermic patients in cardiac arrest. Defibrillation is unlikely to be successful if the core temperature is below 28 °C. Active rewarming techniques include peripheral (forced air warming blankets) and central (warmed, humidified inspired gases; warmed intravenous fluids; warmed cavity lavage – gastric, bladder, thoracic, or peritoneal; intravascular warming devices); or extracorporeal circulation (haemofiltration, cardiopulmonary bypass (CPB), or extracorporeal membrane oxygenation (ECMO)). Victims should not be actively rewarmed above 34 °C and hyperthermia should be avoided.

Supplemental oxygen, non-invasive ventilation or intubation may be required depending on the severity of the respiratory failure and the patient's level of consciousness. Patients may have significant hypovolaemia in the setting of pre-existing dehydration, capillary extravasation and the onset of the systemic inflammatory response syndrome (SIRS). Volume resuscitation and inotropes should be considered in the setting of significant haemodynamic instability.

Systematic physical examination should focus on the respiratory, cardiovascular and neurological systems. Dyspnoea, wheeze and crackles suggest aspiration, while the level of consciousness may have prognostic relevance. Examine for signs of trauma or other medical conditions. Consider decompression illness in scuba divers.

Monitoring should include pulse rate, electrocardiogram (ECG), pulse oximetry (SpO_2), blood pressure, and core temperature. More invasive monitoring such as arterial and central venous pressure monitoring should be considered in the unstable patient. Investigations include an arterial blood gas, full blood count, blood glucose, electrolytes, urea and creatinine, blood alcohol level and toxicology screen, 12-lead ECG and a chest X-ray. Unconscious patients should have a brain CT scan to exclude a primary neurological event or traumatic brain injury and to look for early complications of drowning.

Intensive care management is directed at treating hypoxia, maintaining cardiovascular stability, neuroprotection and prevention and/or treatment of multiorgan failure. Bronchoscopy may be required to remove aspirated debris such as sand. β-adrenergic agonists should be used to treat bronchospasm. Protective lung ventilation with low tidal volumes and moderate levels of positive end-expiratory pressure is used in patients with ARDS. Permissive hypercapnoea should be avoided in patients with neurological injury.

Case reports suggest that surfactant may be useful in paediatric patients with persistent hypoxia following drowning. CPB or ECMO appear attractive for managing hypoxia and temperature regulation (both active rewarming in cases of severe hypothermia and maintenance of therapeutic hypothermia in the immediate post-drowning phase) in drowning victims, however experience is limited and outcomes mixed.[7,9–11] There is no evidence to support the routine use of barbiturates, intracranial pressure monitoring, steroids or prophylactic antibiotics. Empiric antibiotics may be considered in patients who drown in grossly contaminated water.

Mild therapeutic hypothermia to improve neurological outcomes is extrapolated from experimental studies and ventricular fibrillation cardiac arrest trials in adults. It is not proven in asphyxial arrests or in paediatric patients. Patients with return of spontaneous circulation who remain in a coma should be maintained at 32–34 °C for 12–24 hours and then slowly rewarmed at no more than 0.25–0.5 °C per hour. Hyperthermia should be avoided.[2]

Prognosis

Patients who were submerged for less than 5 minutes, resuscitated at the scene and are conscious, breathing and have a pulse on arrival in the emergency department generally have a good outcome. Indeed, patients who present to the emergency department with a Glasgow coma score of 14 or more, have a normal chest X-ray and arterial blood gas, and who are asymptomatic after 6 hours can be discharged with careful follow-up. Approximately one-third of patients admitted to hospital unconscious after drowning will die. Half will survive with no or minimal neurological deficit and the remainder will have moderate to severe neurological impairment.[6]

Many drowning victims have an intermediate risk of poor neurological outcome, and no variable or scoring system consistently predicts the outcome for these patients. A study of paediatric drowning found that all patients with an abnormal initial brain CT died, the most common abnormality being loss of grey–white differentiation.[12] The main clinical features associated with death or poor neurological outcome are listed in Box 3. ◆

Poor prognostic features

Clinical features associated with death or poor neurological outcome include:

- Submersion greater than 5–10 minutes
- Resuscitation not attempted for more than 10 minutes after rescue
- More than 25 minutes of resuscitation
- Glasgow coma score less than 5 or unreactive pupils on arrival to hospital
- Pulseless and apnoeic on arrival to hospital
- pH <7.10 on initial arterial blood gas[7]

Box 3

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Acknowledgement

The authors would like to acknowledge the contribution of the previous authors on this topic — Drs Minto and Woodward.

