Drowning and immersion injury

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Drowning is defined as death following asphyxia as a consequence of submersion or immersion (partial submersion) in liquid. Near drowning has been used to describe the survival of a patient for longer than 24 hours following submersion, however, most authorities recommend that the term no longer be used because some of these patients eventually die.

Worldwide, up to 450,000 people die annually as a result of drowning; at least twice that many are involved in non-fatal submersions. Half of the victims are children, predominantly unsupervised toddlers. The second peak of incidence is in adventurous or inebriated adolescent males. Drowning may follow a precipitating event, particularly in adults:

- primary neurological event (seizure, syncope, stroke)
- primary cardiac event (myocardial infarction, arrhythmia)
- impairment of judgement, conscious level or motor ability by drugs, alcohol or hypothermia
- trauma (cervical spine injury is a particular hazard in shallow water incidents)
- foul play (child abuse, murder attempt, suicide).

Pathophysiology

The pathophysiology of drowning is related to the multi-organ effects of hypoxaemia. The primary determinant of outcome is the occurrence of circulatory arrest, indicative of prolonged asphyxia.

Immersion effects – voluntary breath-holding occurs on initial submersion. This may be accompanied, especially in young children, by the diving reflex: intense peripheral vasoconstriction that promotes bradycardia and preferential blood flow to the heart and brain. At the break point of breath-holding, involuntary gasping occurs and water inhalation occurs. Unconsciousness, progressive bradycardia, asystole and death are inevitable without rescue. If the victim is retrieved from the water and resuscitated, widespread organ dysfunction can be expected. Individuals who drown in

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cold water (< 20°C), particularly small children, rapidly develop hypothermia, which may confer some neurological protection.

Immediate care

It is advisable to lift the victim out prone, to counter the possibility of sudden circulatory collapse on release of external water pressure. Patients who remain conscious are likely to do well. Wet clothing should be removed to allow insulation with thick blankets. This facilitates spontaneous rewarming via shivering thermogenesis.

It may be difficult to distinguish bradycardia from asystolic cardiac arrest in the hypothermic, comatose victim. Immediate (bystander) cardiopulmonary resuscitation (CPR) efforts are crucial to outcome and such efforts are to be encouraged where doubt exists. Unconscious patients are at high risk for aspiration of gastric contents and should be intubated by appropriate personnel, taking care to immobilize the cervical spine.

An unconscious patient should be transferred to a facility that can perform active core rewarming (Figure 1) as soon as possible.

Hospital management

Admission criteria – the decision to admit depends on whether fluid aspiration has occurred. Symptoms and signs include haemoptysis, breathlessness and wheeze, tachypnoea, cyanosis, crackles on chest auscultation, hypoxaemia, and radiographic abnormalities. Subjects who remain asymptomatic and free of clinical signs at 4 hours can safely be discharged.

Decision to resuscitate – in cold water drowning, resuscitation should continue throughout attempts to rewarm. However, in centres without access to cardiopulmonary bypass, restoration of the myocardium to a defibrillatable temperature may not be achieved. In the event of successful return of spontaneous circulation it is suggested that active treatment be continued for at least 24 hours. No factors have been identified that accurately predict death or severe neurological impairment (Figure 2). There are reports of intact recovery despite extreme physiological derangement.

Patients who arrive at the emergency department with prolonged circulatory arrest following warm water (> 20°C) submersion have a dismal prognosis.

Therapeutic goals

- Initiate support of airway, breathing and circulation.
- Commence rewarming using peripheral and core techniques as appropriate.
- Prevent secondary brain injury by providing optimal conditions for cerebral oxygen delivery.
- No specific hospital interventions have been shown to alter outcome. Supportive treatment is indicated for acute lung injury and other organ dysfunction.

Rewarming – restoration of body temperature is a key aspect of management. Techniques to achieve this are outlined in Figure 1. In circulatory arrest below 28°C, the myocardial temperature must be raised as soon as possible for successful defibrillation. This can be accomplished only through active core warming. Following return of spontaneous circulation a controlled restoration of body temperature towards normal is desirable. Pyrexia must be actively prevented because it may exacerbate cerebral injury due to the associated increase in cerebral metabolic rate. The World Congress on Drowning (2002) recommends that victims who remain comatose should be treated with induced mild hypothermia (32–34°C), initiated as soon as possible and sustained for 12–24 hours. This requires intubation, ventilation, sedation and possibly neuromuscular blockade to prevent shivering.

Rewarming techniques for the critically ill

A 60 kg subject with an average specific heat capacity of 0.83 kcal/kg/°C requires 300 kcal of heat energy to raise his temperature from 28 to 34°C

Passive

- Remove wet clothing, insulate with blankets

Useful to limit further heat loss in the pre-hospital phase. Average rate of temperature rise < 0.5°C/hour; in cases other than mild hypothermia active techniques are required

Active

Peripheral (external)

- Forced air warming blanket, hot water bottles

Difficult to control. Can be counterproductive: peripheral vasodilatation can cause a secondary decrease in core temperature. Abolition of shivering may occur. Hyperkalaemia and acidosis may follow reperfusion of peripheries

Central (core) (ascending order of invasiveness)

- Warmed humidified inspired gases ('cascade' humidifier)

Maximum 45°C: delivers 10 kcal/hour, effective and safe

- Warmed intravenous fluids

Maximum 40°C: delivers 10 kcal/litre (all routes)

- Warmed gastro-oesophageal lavage; bladder irrigation; pleural cavity lavage via chest drains

All intracavity methods may precipitate ventricular fibrillation

- Warmed peritoneal lavage or dialysis

Potassium-free dialysate, 40°C, short dwell time

- Intravascular Thermal Regulation System (Alsius CoolGard 3000®)

Controls temperature without removing the blood from the patient via a closed loop internal cooling circuit, the catheter cools or warms the patient's blood as it circulates past the catheter

- Extracorporeal circulation (haemofiltration or cardiopulmonary bypass)

Haemofiltration circuit delivers about 120 kcal/hour at 200 ml/min. Cardiopulmonary bypass obviates need for CPR and affords most effective control over rewarming rate (up to 3000 kcal/hour) and metabolic fluxes (e.g. potassium)

1

Organ damage and treatment

Cerebral damage – irreversible neuronal cell death begins within 5 min of inadequate cerebral oxygen delivery. Significant primary brain injury promotes cerebral oedema, peaking in severity at 24–72 hours after the initial event. The established principles of nursing at 30° head-up tilt, ventilation to low normocapnia and control of cerebral perfusion pressure to greater than 70 mm Hg should be followed. Intracranial pressure monitoring has not been shown to improve outcome after drowning, but may provide useful information. Depending on the history, an early CT scan may be

Predictors of outcome[1]

At scene

- Immersion > 5–10 min

Submersion time is usually an estimate, despite this it is a good surrogate of asphyxia time and correlates well with outcome

- Presence of cardiac arrest

Survival in individuals maintaining spontaneous circulation is > 98% , compared with 20% in those who lose their output

- Bystander CPR

Bystanders may be dismayed by the appearance of the victim and erroneously consider resuscitation efforts to be futile. Studies suggest that the only victims who survive are those who are immediately resuscitated at the scene.

- Water temperature

The classification of drowning as warm or cold depends on the temperature of the water (> or < 20°C), not the victim. Rapid brain cooling in icy water may be protective. There are a few reports of children surviving intact after long submersion in water < 5°C. However, if a victim has been submerged in water > 5°C for longer than 25 min, the outcome is death or a persistent vegetative state

On arrival at emergency department

- Asystole on arrival/CPR duration > 25 min

Severe asphyxia likely

- Dilated, non-reactive pupils and arterial pH < 7.0

Acidosis and lactataemia usually correlate with poor outcome in cardiac arrest. However, in drowning these are due to extremely acute cellular hypoxia. Rapid restoration of perfusion may reverse these profound metabolic derangements quickly. Thus initial pH and lactate levels are of doubtful significance

- Dilated, non-reactive pupils and Glasgow Coma Score < 5

Suggests severe primary brain injury

- Poor Paediatric Risk of Mortality (PRISM) score

Despite case reports, age has no independent association with outcome. PRISM score < 16 implies negligible risk, a score > 24 predicts death or severe neurological impairment. In patients with intermediate PRISM scores, a reliable prognosis is impossible to establish. PRISM scoring at the time of admission to PICU is not helpful

In the critical care unit

Formal neurological assessment should be deferred until 24 hours after immersion

- Absence of purposeful motor response

GCS motor score < 5 indicates poor prognosis

- Absence of brainstem reflexes

Absent pupillary responses and spontaneous respiration. Sedation modifies these signs

CT scan at about 36 hours, showing abnormality (e.g. loss of grey–white matter differentiation) is useful corollary evidence

[1]The influence of varying levels of hypothermia on these predictors has not been well quantified.

2

useful to exclude a primary neurological cause. Seizure activity must be controlled promptly with benzodiazepines.

Pulmonary effects – immediate local effects of water aspiration (salt or fresh) include bronchospasm, abnormal blood flow distribution, pulmonary oedema and ventilation–perfusion mismatch. Pneumonitis may follow aspiration of swimming pool chlorine or vomitus. Systemic steroids are not useful in treatment. Up to 70% of symptomatic survivors develop acute lung injury or acute respiratory distress syndrome, through loss of surfactant function leading to reduced compliance, segmental alveolar collapse and transcapillary fluid leak. Management of the consequent hypoxaemia requires supplemental oxygen and a protective ventilation strategy, though permissive hypercapnoea may be contraindicated if cerebral oedema is present. Blood gas interpretation is complicated by the increased solubility of O_2 and CO_2 in cold blood. To avoid missing significant hypoxaemia it must be appreciated that the true in vivo PaO_2 in a cold patient is lower than that measured at normothermia. $PaCO_2$ and pH corrected to 37°C are an acceptable guide to interventions.

Cardiovascular system – the ECG in hypothermia characteristically shows bradycardia, progressing to complete heart block at lower temperatures. A positive deflection after the QRS complex, the J wave, may appear. Below 28°C refractory ventricular fibrillation commonly supervenes. Extravasation from systemic and pulmonary capillaries promotes hypovolaemic shock, exacerbated by cold diuresis (renal inability to conserve water). A systemic inflammatory response syndrome (SIRS) with profound vasodilatation may occur following resuscitation. Rapid volume expansion is necessary. If severe acidaemia and hypothermia are present, they accentuate the low cardiac output state. Lactic acidosis normally corrects spontaneously over several hours following restoration of tissue oxygen delivery. Failure to do so despite adequate volume replacement suggests renal, hepatic or bowel ischaemia.

Infection – stagnant water is colonized by Gram-negative bacteria and more unusual pathogens. Aspiration of such fluid promotes pneumonia and may lead to systemic infection. Prophylactic antibiotics are of unproven benefit but are prudent if the subject was submerged in grossly contaminated water. Some authorities advise an outpatient chest radiograph after 2 weeks for all patients.

Outcome

A quarter of hospital admissions alive at 24 hours ultimately die, and a further quarter have a poor neurological outcome.

FURTHER READING

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