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Drowning, Near Drowning and Immersion Syndrome

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Introduction

Drowning is a common cause of accidental death and often affects young healthy individuals. Early rescue and resuscitation in order to minimise damage to the central nervous system and the identification and management of concomitant injuries, will determine the subsequent quality of life. There are dramatic examples of both adult and paediatric victims of prolonged submersion with cardiac arrest who have survived to discharge with normal or near normal functional status (1) thanks to modern critical care medicine. This article is intended to update medical and paramedical staff on current terminology and the emergency management of submersion injury. Particular attention is drawn to the fact that significant morbidity may still arise in the apparent survivor, up to 24 hours after successful rescue.

Epidemiology

Worldwide there are 3.5 deaths/100,000 population caused by drowning and in 2002 427 people drowned in the United Kingdom (2,3). This is in comparison to the 3508 fatalities in road accidents in 2003 or 578 deaths in fires in 2002. 35% of the total deaths were in men aged between 15 and 45 years old and only 17 drownings were reported in the under 5s. Alcohol was found to play a part in 17% of all drownings in that year with the vast majority occurring in stretches of open water such as rivers, lakes and costal areas though there was still a significant number occurring within the home environment (baths and ponds). Drowning is also responsible for 60% of the deaths that occur in SCUBA diving.

The Military Context

Men and women from all three services may be exposed to injury as a result of submersion. Any conventional or non-conventional military operation, adventurous training or recreational activity may involve exposure to a water hazard. Particularly vulnerable are submariners and divers, and the sub-specialty of underwater medicine has evolved to deal with the unique hazards faced by these personnel. Recent incidents involving the Russian submarines Kursk and AS-28 (4,5) highlighted the potential in a modern fleet for a major incident involving multiple casualties when a crew is required to exit a stricken submarine. However, drowning and near drowning have stalked the survivors of shipwreck down through the centuries, particularly during World War II when thousands of Royal Navy and Merchant Marine sailors were cast into the Atlantic as a result of submarine attack upon supply convoys. Specialist medical and technical teams have evolved to fill capability gaps, such as the Subsunk Parachute Assistance Group (SPAG). This team is able to deploy world-wide at very short notice and to parachute onto the scene if necessary to supervise the medical care of an escaped submarine crew. However, any military or civil hospital may be required to manage the victim of a recreational or industrial near drowning incident. Prompt and effective critical care may save life and will minimise secondary morbidity.

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Terminology

Drowning is defined as death due to asphyxia caused by submersion in fluid (6,7) (usually water).

Near Drowning is defined as initial survival at least beyond 24 hours of an individual after suffocation due to submersion in fluid. It does not necessarily lead to long term survival and is associated with secondary complications, which require further medical management.

Immersion Syndrome is sometimes used to describe both pathophysiological entities although strictly speaking it refers to sudden death immediately following submersion in cold water (8).

Post Immersion Syndrome or Secondary Drowning is an acute deterioration in respiratory function in a patient subjected to a submersion incident, who appears to be well at initial presentation.

Pathophysiology

Cold Shock Response

This refers to the first three to four minutes of cold water (head out) *immersion* rather that submersion. It consists of peripheral vasoconstriction, the gasp reflex, hyperventilation and tachycardia. Vagal arrest may supervene (Immersion Syndrome), or the victim may become submersed and thus subject to drowning. Respiratory failure and cerebral hypoxic injury are the major threats to life. Respiratory failure and cerebral hypoxicinjury are the major threats to life after submersion. There may be associated traumatic injury, hypothermia and aspiration pneumonitis. Acute Respiratory Distress Syndrome (ARDS) and Acute Lung Injury (ALI) pose management challenges in the Intensive Care Unit (ICU).

Hypoxia (7,9,10) is the principle mechanism of injury in near drowning and occurs through several mechanisms. In the most basic form submersion in water results in cessation of normal respiration and a sudden reduction in alveolar concentration of oxygen. This causes the victim to gasp with a subsequent intake of water. At first there may be violent laryngospasm and bronchospasm, preventing ingress of water into the lower airway, but as hypoxia supervenes, the vocal cords relax and water enters the lungs, exaggerating the hypoxia. Aspiration leads to changes in pulmonary surfactant, and here there is a difference between saltwater and freshwater. In saltwater aspiration acute pulmonary oedema occurs due to the drainage of protein rich fluid from the intravascular space into the alveoli; this is because saltwater has 3-4 times the hypertonicity of blood. In freshwater aspiration surfactant is inactivated resulting in alveolar collapse (atelectasis), leading to an increase in ventilation/perfusion mismatch (shunt) within the lungs.

Pulmonary parenchymal damage occurs due to the irritant effect of water within the lungs (7). As a consequence, a protein rich transudate floods the alveoli further impairing gas exchange (secondary drowning) and this may occur up to 12 hours after the initial event. 70% of submersion victims also aspirate mud, algae and vomitus as well as water, which may cause an aspiration pneumonitis. Non-cardiogenic pulmonary oedema may result from direct pulmonary insult, surfactant loss, inflammatory contaminants and cerebral hypoxia.

Hypoxia is sensed by arterial chemoreceptors, leading to activation of the autonomic nervous system (7). A subsequent bradycardia leads to a reduction of myocardial oxygen consumption, and an increased tolerance to the hypoxic episode. Vasoconstriction to non-vital organs also occurs (e.g. skin and splanchnic vessels), thus conserving available oxygen for the heart and brain. This vasoconstriction may be strong enough to decrease or obliterate peripheral pulses, and this effect may be exaggerated in the hypothermic victim.

Hypothermia is a concomitant hazard due to prolonged immersion even in temperate climes. Wind and surface spray over exposed body surfaces, low water temperatures, lack of insulation and alcohol ingestion are factors that will accelerate the drop in core temperature.

Aspiration of water usually occurs in such low volumes that it does not affect the haemoglobin level or electrolyte balance, although hypercalcaemia and hypermagnesaemia have been reported following submersion in the Dead Sea. Rhabdomyolysis (11) may occur if the hypoxic insult to the muscles is extensive and the subsequent myoglobinaemia may precipitate acute tubular necrosis and consequent renal failure. Rhabdomyolysis (11) may occur if the hypoxic insult to the muscles is extensive and the subsequent myoglobinaemia may precipitate acute tubular necrosis and consequent renal failure.

Fig 1. Helicopter winching in action.

Circum-Rescue Collapse

Circum-rescue circulatory collapse may also occur following rescue from immersion in water (7,9,12, 13). In the water, there is an increased hydrostatic pressure around the victims legs and trunk which results in an increase in venous return and hence an increase in cardiac output. This increase in central volume is sensed as hypervolaemia by the body and thus a diuresis and salt loss (natriuresis) will occur. Peripheral vasoconstriction will occur due to the relative cold temperate of the water, even in temperate climes, resulting in a further increase in venous return and exacerbating this response. In this way the victim's intravascular volume becomes depleted. One suggested mechanism leading to circulatory collapse is that the myocardium becomes stressed due to increased venous and arterial pressures resulting in increased catecholamine release. Coupled with hypoxia, the increase in circulating catecholamines may provoke cardiac dysrythmias. A second theory is that removal from the water caus-

Fig 2. Helicopter stretcher.

es a sudden release in the hydrostatic pressure around the abdomen and legs, with a consequent venous pooling in the lower limbs and reduced venous return to the heart. The resultant acute decrease in coronary perfusion may provoke ventricular fibrillation or acute myocardial ischaemia, causing death.

Prehospital Management

Prehospital care commences with the rescue phase during which the victim is safely and rapidly removed from the water. 'Scene safety' is paramount and there are a myriad of examples where would-be rescuers have become secondary victims through failure to appreciate the hazards posed by the environment. Extraction from the water should ideally be on a long spinal board or in a purpose designed litter (Figs 1 & 2). Cervical and spinal immobilisation should be employed when injury has occurred, although the need for continued spinal precautions should be actively reviewed once the rescue phase is complete. Variations in body position may provoke dysrythmias in the severely hypothermic victim. This is because the cardiovascular system cannot cope with fluid shift changes brought about by being moved from the supine to the vertical position for instance. For this reason hypothermic victims should be managed supine, preferably in a litter. Some search and rescue (SAR) helicopters employ a double strop to winch victims from the water. One strop passes around the trunk beneath the axillae, the other around the leg beneath the knees, allowing the victim to be winched in the foetal position. This is said to reduce the incidence of circum rescue collapse following prolonged immersion (9), which occurs due to the sudden release of the protective hydrostatic pressure around the victim's legs and trunk. Primary survey immediately follows the rescue phase. Submersion injury alone without traumatic injury is not an indication for C-spine immobilization (14). However, diving and surfing incidents in which there has been shallow water impact, significantly increase the risk of cervical spine injury due to the axial load onto the vertebral column, and in these cases there must be a low threshold for full spinal immobilisation.

The airway should be cleared, suctioned as necessary and maintained with assisted ventilation as required. Supplemental oxygen should be administered at the highest possible concentration available (in absence of saturation monitoring), or at a rate to maintain saturations (SpO_2) above 92% when conservation of oxygen supply is an issue. In cardiac arrest the victim should be intubated without drugs. In the unconscious and hypoxic, but self-ventilating victim, skilled providers may undertake rapid sequence intubation (RSI) and provide intermittent positive pressure ventilation (IPPV) with positive end-expiratory pressure (PEEP). This will secure the airway, treat hypoxia, prevent atelectasis and optimise gaseous exchange. However, the provider must consider concomitant barotrauma resulting in pneumothorax / tension pneumothorax, especially in diving incidents, and be prepared to site an intrapleural drain. If the patient is hypotensive or tachycardic then

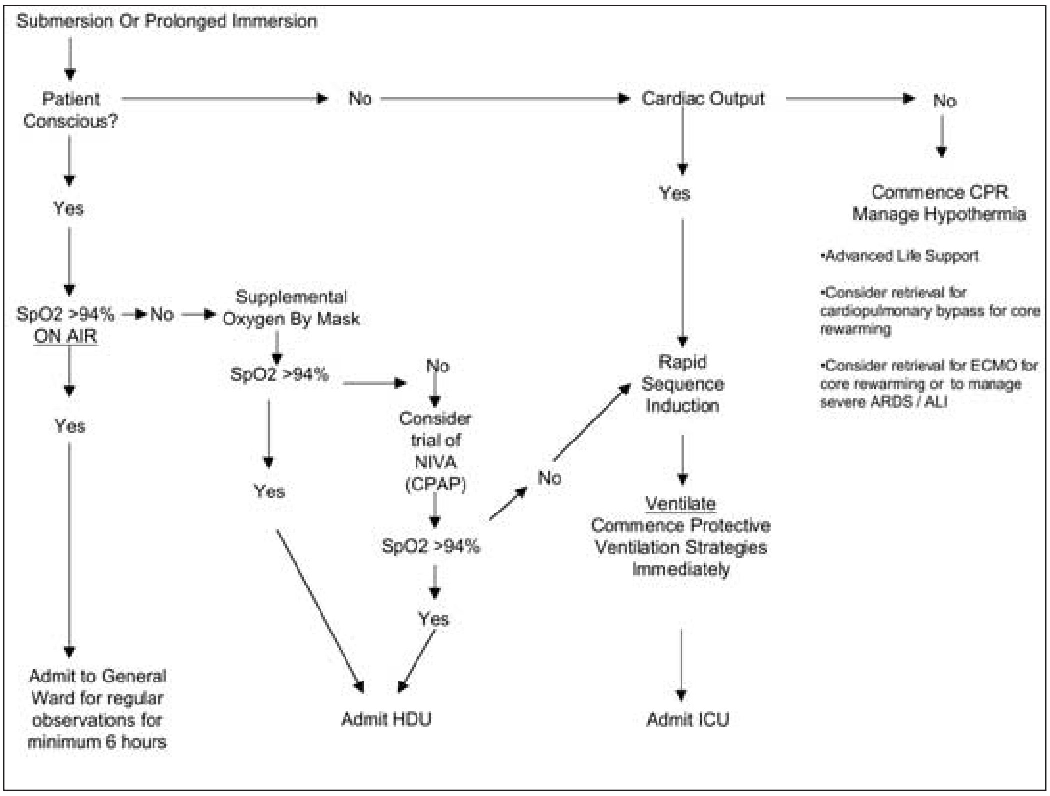

Fig 3. Treatment Algorithim

judicious use of (warmed) intravenous crystalloid fluid boluses will be required.

In cases of cardiac arrest cardiopulmonary resuscitation (CPR) should be commenced and continued through to the hospital facility as hypothermia may be a confounding factor making the detection of vital signs difficult in the field. Remember the adage that hypothermic victims are not dead until they are 'warm and dead'.

Any secondary survey must concentrate on life and limb threatening injuries only, and in any case must not delay onward transport to definitive care. The correct disposition is to a hospital with 24-hour ICU facilities.

Definitive Care

This phase focuses on continued resuscitation, correction of respiratory failure and management of concomitant injuries. All patients require the following investigations: - full blood count (FBC) and coagulation profile, urea and electrolytes (U&E), serum glucose and creatine phosphokinase (CPK), arterial blood gas estimation (ABG), electrocardiograph (ECG), chest X-ray (CXR) and urinalysis (MSU) for myoglobinuria. A toxicology screen may be useful in differentiating the unconscious victim. Tetanus immunostatus should be checked and a booster or course of treatment given as necessary (6, 11, 12).

Patients can be divided into two subgroups: - The first group is those who are self-ventilating and who have a normal level of consciousness - these patients only require supplemental oxygen to maintain their SpO_2 >94%. Nebulised bronchodilotors may be required to control bronchospasm. They require hourly observations to detect post immersion syndrome or aspiration pneumonitis, either on a general ward or in a High Dependency Unit (HDU) setting (see Figure 3) (11). If a patient's respiratory function deteriorates, but they are alert, unlikely to vomit and can comply with mask therapy then they should be considered for non-invasive ventilatory assistance (NIVA). Those who do not meet these criteria, or who deteriorate further, should undergo RSI and be managed as detailed below. Patients managed in the ward or HDU setting must be observed for a minimum period of six hours, and prior to discharge the patient must have documented normal blood gases and a normal core temperature and be advised to return if they suffer any deterioration in symptoms or if they develop a fever within the subsequent few days.

The second group of patients are those patients who have inadequate ventilation secondary to decreased conscious level or due to the initial pulmonary injury. Patients with significant submersion injury are at very high risk for compounding their respiratory failure through ALI or ARDS. These patients require early controlled ventilation upon arrival in the emergency department, with subsequent management in the ICU. Ideally mechanical ventilation should potentiate alveolar recruitment and optimise intra pulmonary gas distribution. Inappropriate ventilator management may exacerbate respiratory failure. Ventilator – associated lung injury (VALI) may occur with 'traditional' high tidal volume (TV) – low PEEP ventilator settings. In the submersion victim further parenchymal lung damage may occur due to the overdistension of aerated lung (stretch) and the repeated opening and closing of the collapsed, derecruited lung (shear) (14). This may disrupt the normal alveolar integrity and perpetuate the inflammatory response (14). Critical care may begin at the point of rescue in the hands of skilled providers; otherwise it must begin in the emergency department with the employment of ventilator management that is effective and does no further harm to the patient.

Recommendations For Ventilation (15)

These are based upon the 'open lung technique', which aims to optimise lung mechanics and to limit iatrogenic damage caused by mechanical ventilation.

1. Manual ventilation. When ventilating by reservoir – bag, e.g. prehospital, each breath should be administered so that the chest is seen to just rise and fall. This prevents excess volume and pressure. Aim for an $Sp0_2$ of 93 – 97% and end-tidal carbon dioxide ($ETCO_2$) of 4.5 – 6.0kPa (35 – 45mmHg)
2. PEEP. Set PEEP at >10 cm H_2O initially. Most alveolar derecruitment occurs in supine patients at PEEP levels between 10 – 15 cm H_2O. Extensive parenchymal injury will require increased PEEP. Hypotension suggests under-filling, indicating further fluid replacement or inotropic support.
3. Oxygenation. PEEP or mean airway pressure should be increased to maintain the highest possible PaO_2 / FiO_2 ratio. Aim for PaO_2 of 60 – 80mmHg (8 – 10kPa) using the lowest possible oxygen concentration. High oxygen concentrations have been shown (paradoxically) to increase at atelectasis and to cause toxic parenchymal damage through free radical formation (15).
4. Peak/Plateau airway pressure. This should be limited to <35cm $H_2O$to minimise VALI. This can be achieved by decreasing TV, decreasing respiratory rate and increasing inspiratory time. Change to pressure mode ventilation +/- inverse ratio ventilation on advanced ventilators.
5. Tidal Volume. Limit TV at 6 – 8ml/kg. Volutrauma may result from high TVs causing over distension, or from high PEEP without a corresponding limitation in TV.

6. Permissive hypercapnia. In ARDS with a marginal PaO_2/FiO_2 ratio, high PCO_2 with corresponding acidosis down to pH 7.2 has been shown to be tolerated without adverse cardiovascular compromise, in exchange for ventilator settings that limit further parenchymal damage.
7. Patient turning, suctioning and chest physiotherapy will improve gas exchange.
8. Consider intermittent prone position ventilation if other methods of recruitment fail.
9. Beware barotrauma especially in diving incidents
10. Bronchioalveolar lavage is useful to obtain samples for culture to optimise therapy in cases of aspiration.

Rewarming

Patients who are hypothermic (core temperature <35°C) require active rewarming. The patient's cardiovascular status dictates the method employed, and so the rate at which they are rewarmed. Those who are haemodynamically stable can be rewarmed using convective or forced-air warming (BairHugger®, Arizant Inc, Eden, Prairie, MN55344, USA) or resistive warming (Gera Therm system®, 98,716 Geschwenda, Germany) methods with a maximum rate of warming of 1°C/hour. Those whom are haemodynamically unstable or in cardiac arrest must be rapidly rewarmed. This is ideally achieved using cardiopulmonary bypass (CPB) techniques (16) or veno-veno haemodialysis (e.g. Prisma system®, Gambro Hospal Ltd, Huntingdon, Cambs, UK) and can produce a temperature rise of 5-10°C/hour. Recently dramatic results have been achieved using Extra-corporeal Membrane Oxygenation (ECMO) (17,18). If none of these technical modalities are available then the patient may be rewarmed through bladder irrigation and pleural lavage using warmed fluids. A recent meta-analysis has demonstrated the efficacy of pleural lavage when advanced techniques such as CPB or ECMO are not available and retrieved to a regional tertiary facility is either impossible or will be subject to an unacceptable prolonged delay (19). Those patients who are in cardiorespiratory arrest require full resuscitation in accordance with current Advanced Life Support (ALS) guidelines, and active rewarming up to a core temperature of 33°C. Consideration should be given to the use of an external cardiopulmonary resuscitator system to ensure prolonged consistent compression thus maintaining adequate circulation.

Corticosteroids (20) have not shown any proven benefit in long-term outcome and therefore, should not be considered in the management of near-drowning victims unless otherwise indicated.

The use of prophylactic antibiotics also has no proven benefit in victims of near drowning and should be reserved for those with suspected or proven infection. However, submersion in a spa or hot-tub, or in polluted water is an indication for an anti-pseudomonal third generation cephalosporin as part of the patient's emergency management.

Prognostic Indicators

Despite numerous attempts to create scoring systems that will predict survival and long term neurological recovery after submersion injury (21), none have been validated for clinical use. In cases of cardiorespiratory arrest at the incident scene, in the presence of an obvious fatal injury, or where it is clear that submersion has been very prolonged, life may be pronounced extinct. In all other cases advanced life support should be instituted and cardiopulmonary resuscitation continued through to the emergency department where a full evaluation can proceed as to the futility, or otherwise, of continued resuscitation. Once critical care has been instituted, the failure to achieve return of spontaneous circulation following rewarming to 33°C, or a measured serum potassium >10 mmol/l are indications to pronounce life extinct (11).

Novel Therapies

Extracorporeal membrane oxygenation (ECMO) is a novel therapy that has been employed in several cases of near drowning (17,18) with dramatic results in both children and adults on occasion. Several patients have survived to discharge with an excellent functional status. Consideration should be given to referral to a regional centre with the capacity for ECMO in cases of submersion injury with hypothermic cardiorespiratory arrest, or in cases of near drowning where severe ARDS or ALI complicates their ICU management.

Surfactant therapy (22) is currently undergoing phase 3 trials in the treatment of ARDS and ALI. Surfactant may in the future become part of the early therapeutic management of submersion injury where patients require early ventilation, or where initial survivors develop post immersion syndrome and require ventilatory assistance.

Therapeutic hypothermia (23) is emerging as a therapy in survivors of cardiorespiratory arrest and has been employed experimentally in some survivors of submersion. Some benefit has been demonstrated in patients maintained at 33°C for 12 hours, but the technique has not yet been validated and in any case is not recommended in children.

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