Chapter 18

DROWNING

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Drowning is a leading cause of death worldwide, occurring mainly in low- and middle-income countries and particularly affecting children aged 1 to 4 years due to limited control over their movements (Leavy *et al.*, 2023; Batista *et al.*, 2023). The mechanism involves water aspiration, damaging surfactant and leading to alveolar edema, resulting in a syndrome similar to acute respiratory

distress syndrome (ARDS) (Thom *et al*., 2021). Rapid action by healthcare professionals is crucial to prevent death and neurological sequelae due to hypoxia (Batista *et al*., 2023). Drownings rarely occur due to a single cause, making a one-size-fits-all solution unfeasible (Wallis *et al*., 2015).

Drowning is a significant public health challenge, with over 230,000 fatal victims recorded in 2019, with 90% in underdeveloped countries, and men being twice as likely to drown compared to women due to greater exposure to aquatic activities (Leavy *et al*., 2023). Initial management follows the drowning survival chain: prevention, recognition, flotation, water removal, and provision of appropriate care, prioritizing rescuer safety (Batista *et al*., 2023). The scarcity of clear evidence prevents specific treatment recommendations, emphasizing the need for more research (Thom *et al*., 2021).

In 2017, there were 295,000 unintentional drowning deaths, highlighting the urgency of standardizing care to improve outcomes (Peden; Taylor and Franklin, 2022). In prehospital care, the drowning survival chain is applied, and the victim's state of consciousness is checked, calling for technical help and initiating resuscitation when necessary (Batista *et al*., 2023). In hospital management, assessing the airways, breathing, circulation, and temperature is fundamental, using pulse oximetry, blood pressure, body temperature, and electrocardiography monitoring, as well as laboratory tests to guide clinical conduct (Batista *et al*., 2023).

EPIDEMIOLOGY

Drowning is one of the three leading causes of unintentional fatal injuries, with an estimated 360,000 annual deaths worldwide (Willcox-Pidgeon *et al*., 2020). Mortality rates vary between populations due to different public health strategies and injury prevention interventions that do not always consider social, educational, cultural, and environmental determinants such as ethnicity, cultural origin, beliefs, and socioeconomic status. These determinants are interlinked in social and policy norms, influencing health outcomes and creating inequalities. High-risk populations include ethnic minorities, indigenous peoples, migrants, rural residents, and people in remote environments. Other risk factors include age, with higher prevalence in children (0-18 years), male sex, environmental context, and alcohol consumption (Willcox-Pidgeon *et al*., 2020).

In 2019, more than 230,000 people lost their lives to drowning, with 90% of these cases occurring in low- and middle-income countries (Leavy *et al*., 2023). Two-thirds of these deaths involved people aged 15 years or older. Risk factors for adults include alcohol consumption, swimming alone, and not wearing life jackets, as well as socio-environmental factors such as inadequate water safety skills, dangerous water conditions, and unsafe infrastructure. Globally, men have a higher risk of drowning, with a mortality rate twice that of women. This disparity is due to greater male exposure to water and involvement in riskier

activities and behaviors (Leavy *et al.*, 2015). In regions like the Eastern Mediterranean, additional factors such as migration and conflicts contribute to the high drowning rate, highlighting the need for specific interventions for these populations (Peden; Isin, 2022).

Characterized by respiratory impairment due to immersion or submersion in liquids, drowning can result in fatality or sequelae, being more prevalent in individuals with pre-existing medical conditions such as epilepsy, dementia, schizophrenia, psychotic disorders, cardiac arrhythmias, and other chronic conditions (Peden; Taylor; Franklin, 2022). These factors increase the risk of drowning, which can be accidental, intentional, or suicidal, especially in psychiatric patients. The management and prevention of drowning require a comprehensive approach, considering all these factors. The prevalence of drowning is high in pediatric patients, being the leading preventable cause of death in children aged 1 to 4 years, with severe neurological sequelae in 5 to 10% of surviving victims (Batista *et al.*, 2023). The prognosis depends on the interval between submersion and rescue, with better outcomes when rescue occurs in less than six minutes (Batista *et al.*, 2023).

Risk factors for drowning include intrinsic elements such as male sex, age 0 to 4 years, adolescents, history of neurological disorders, and cardiomyopathies, and extrinsic factors such as alcohol and drug consumption, low education, rural residence, lack of pool fencing, and lack of swimming equipment. Factors associated with worse outcomes include age under 5 years, submersion time over five minutes, higher Szpilman score, lower Glasgow coma scale on admission, water temperature (cold), hypothermia below 30°C, acidosis, hyperglycemia, hypernatremia, hyperkalemia, elevated lactate and liver enzymes, delay in starting cardiopulmonary resuscitation (CPR) or duration over 30 minutes, and abnormal chest x-ray (Batista *et al.*, 2023). Understanding these risk factors is essential to implementing effective preventive strategies. For example, constant supervision of young children, swimming instruction, and the implementation of fences around water bodies can significantly reduce childhood drowning rates (Tyler *et al.*, 2017).

DIAGNOSIS

When water comes into contact with the airways, protective reflexes such as coughing and laryngospasm occur, leading to hypoxia. Hypoxia results in the relaxation of the respiratory muscles, ceasing laryngospasm and allowing more water to be aspirated into the lungs. This causes mild acidosis, apnea, loss of consciousness, cerebral hypoxia, and arrhythmias. Simultaneously, cytokine release, alveolar-capillary membrane integrity disruption, and intense pulmonary edema occur (Batista *et al.*, 2023).

In the cardiovascular system, initially, there is tachycardia, followed by a reduction in heartbeats, pulmonary hypertension, and decreased cardiac output (Cibulski *et al.*, 2023). Pulseless electrical activity sets in, evolving to cardiac arrest due to asystole. Water temperature can influence the progression time of these events; in cases of rapid hypothermia, the evolution to asystole can last up to an hour (Cibulski *et al.*, 2023).

In drowning emergencies, resuscitation must be initiated immediately, and the victim must be transported directly to an emergency service. The goal is to restore effective circulation, including respiratory support, pulse oximetry, electrocardiography, blood pressure, and body temperature measurement. Management depends on the severity and risk of death, potentially including oxygen administration via nasal catheter, face mask, or non-invasive ventilation (NIV). In more severe cases, mechanical ventilation (MV) is considered (Batista *et al*., 2023).

If there is no pulse, continuous chest compressions are necessary. In cases of poor perfusion, supplementary volume such as crystalloids or blood can be administered, and vasoactive drugs like dobutamine may be used in pediatric patients. Clinical, laboratory, and echocardiographic evaluation is essential, including a complete blood count, electrolytes, glucose, arterial blood gas analysis, renal function, liver enzymes, and chest x-ray. Antibiotics are generally not indicated unless there is suspicion of water contamination, which can cause fatal pneumonia. In such situations, broad-spectrum antibiotics are considered. Diuretics may be indicated in case of hypervolemia or reduced urine output after volume restoration (Batista *et al*., 2023).

It is crucial to monitor oxygen saturation (at least 90%) for 6 to 24 hours to prevent hypothermia. In cases of apnea, tracheostomy and intubation are recommended. Children are more prone to hypothermia due to the body mass-to-surface ratio, requiring specific warming care. Mild hypothermia (32-35°C) can be treated with passive rewarming using blankets or thermal blankets, while moderate cases (28-32°C) may require heated oxygen and warmed intravenous infusions, with strict monitoring to avoid rewarming shock. Severe hypothermia (<28°C) requires active internal warming measures with saline lavage and external forced-air warming. If there are signs of shock, intravenous or intraosseous saline solution can be administered, and inotropes may be necessary in case of cardiac dysfunction (Cibulski *et al*., 2023).

TREATMENT

Effective treatment of drowning is essential to improve survival rates and minimize long-term sequelae. Typical interventions include cardiopulmonary resuscitation (CPR), adequate ventilation and oxygenation, advanced life support, and body temperature control, each applied as per clinical need (Leavy *et al*., 2023; Wallis *et al*., 2015; Sampaio *et al*., 2022).

Cardiopulmonary resuscitation (CPR) is the initial and most vital intervention in drowning treatment, to be initiated as quickly as possible to restore blood circulation and breathing. Research indicates that CPR performed by bystanders can significantly increase survival chances, especially when followed by advanced medical care in a hospital. Early application of CPR is widely recognized as an essential life-saving measure (Leavy *et al*., 2023; Wallis *et al*., 2015).

Adequate ventilation and oxygenation are fundamental to prevent hypoxia and brain damage, often requiring the use of mechanical ventilators and other respiratory support devices. In severe cases, mechanical ventilation may be necessary to maintain adequate oxygenation levels until spontaneous respiratory function is restored. Studies indicate that effective ventilation is crucial to improving outcomes in patients who suffered severe drowning (Sampaio *et al.*, 2022). For patients with spontaneous breathing, oxygen can be administered via nasal catheter, face mask, or non-invasive ventilation (NIV). However, for those with a Glasgow coma scale (GCS) score below 8, apnea, or progressive respiratory distress, invasive mechanical ventilation (MV) should be considered, offering intermittent positive-pressure oxygen or positive end-expiratory pressure. High concentrations of oxygen should be provided to achieve a saturation above 92%. Protective ventilation is recommended, with tidal volume between 4-6 mL/kg and plateau pressure below 30 cmH2O. The goal is to maintain PaO2 between 55 and 80 mmHg and reduce FiO2 as quickly as possible to avoid lung injury caused by hyperoxia (Batista *et al.*, 2023).

Advanced life support, including the use of vasopressor medications and continuous monitoring, is vital to stabilize severe patients and prevent multiple organ failure. In many cases, hemodynamic support is necessary to maintain adequate perfusion of vital organs. The implementation of advanced life support protocols has been shown to significantly improve survival rates and clinical outcomes in critical patients (Leavy *et al.*, 2023).

Body temperature control is a crucial aspect of drowning treatment, especially in victims exposed to cold waters. Gradual and controlled body temperature recovery helps prevent additional complications such as cardiac arrhythmias. Proper hypothermia management, using passive or active warming techniques, is essential to ensure the patient's hemodynamic and neurological stability. Additionally, monitoring and treating pulmonary complications, such as acute respiratory distress syndrome (ARDS), are essential for the patient's full recovery (Wallis *et al.*, 2015; Sampaio *et al.*, 2022).

Clinical evaluation should guide the request for laboratory and imaging tests. It is recommended to request a complete blood count, electrolytes, glucose, arterial blood gas analysis, renal function, liver enzymes, and chest x-ray (CXR). As evidenced in the current literature, worse outcomes are associated with low pH, bicarbonate alteration, hypernatremia, hyperkalemia, acute kidney injury, elevated lactate, glucose, and liver enzymes. Cervical spine x-rays may be indicated if cervical injury is suspected, as well as other complementary tests depending on the clinical picture (Batista *et al.*, 2023).

The management of drowning has evolved significantly with the introduction of new treatment modalities and emerging tools. Among the most promising interventions are advanced resuscitation techniques, innovative technologies for monitoring and life support, and emerging pharmacological approaches aimed at improving patients' clinical outcomes. These innovations are increasingly being incorporated into treatment protocols to provide a more effective response to drowning incidents (Wallis *et al.*, 2015).

One of the most notable advances is the use of innovative ventilation devices and advanced respiratory support techniques. New non-invasive ventilation modalities are being explored to optimize oxygenation and carbon dioxide removal in drowning patients. These techniques aim to reduce the risk of complications associated with invasive ventilation, such as ventilator-induced lung injury, and improve clinical outcomes for patients (Leavy *et al*., 2023; Wallis *et al*., 2015).

Emerging technologies such as advanced sensors and artificial intelligence for continuous vital signs monitoring are revolutionizing drowning management. These devices enable early detection of clinical deterioration, facilitating rapid and targeted interventions. Remote monitoring systems are also being implemented to follow patients during the recovery phase, ensuring any complications are promptly identified and treated (Leavy *et al*., 2023; Wallis *et al*., 2015).

Emerging pharmacology is also playing a crucial role in drowning treatment. New pharmacological agents, such as inflammatory response modulators, are being investigated to reduce damage caused by hypoxia and systemic inflammation that often accompany drowning. The administration of medications like corticosteroids and antioxidants has shown potential to improve neurological recovery and reduce the risk of long-term sequelae (Leavy *et al*., 2023; Sampaio *et al*., 2022).

Extracorporeal membrane oxygenation (ECMO) is an important resuscitation tool for the hypothermic drowning victim. The treatment focuses on rewarming and oxygenation, in addition to providing circulation. ECMO can be delivered in veno-venous or veno-arterial modalities. The veno-venous type is useful for patients who have regained a perfusing heart rhythm but cannot perform gas exchange due to alveolitis, pulmonary edema, or surfactant deactivation induced by aspiration. The veno-arterial ECMO is considered for patients without a perfusing heart rhythm, thus providing circulatory support. Besides providing rewarming, oxygenation, and circulation, ECMO can also correct metabolic alterations. Providing circulatory support is critical because over 90% of patients with severe hypothermia experience cardiac arrest. Rewarming causes the heart rhythm to transition from asystole to ventricular fibrillation before returning to sinus rhythm, and ECMO maintains hemodynamic stability and circulatory support during this transition (Bauman *et al*., 2021).

Despite the benefits of ECMO, mortality remains high. In drownings with hypothermia and cardiorespiratory arrest, there is an inherent risk of severe neurological damage in survivors, which some patients may consider worse than death. Other obstacles include low availability and high cost, in addition to the need for specialized professionals. However, ECMO is a lifesaving therapy in drowning cases (Bauman *et al*., 2021).

Evaluating the effectiveness and safety of these emerging treatments is crucial for their incorporation into clinical protocols. Rigorous clinical studies and systematic reviews are needed to validate the benefits of these new approaches. The existing literature suggests that, although promising, these innovations should be implemented with caution

and accompanied by continuous monitoring to ensure patient safety. The integration of new technologies and treatments should be done gradually, based on solid evidence and well-established clinical practices (Leavy *et al*., 2023; Wallis *et al*., 2015; Sampaio *et al*., 2022).

Drowning treatment presents several significant challenges that can negatively impact the effectiveness of interventions and patient recovery. One of the main challenges is the variability in the circumstances of each drowning incident, which requires personalized and rapid approaches to treatment. Additionally, the availability and adequacy of emergency resources at the incident site are crucial for first aid and can determine the patient's survival. This variability complicates the standardization of treatment protocols, which can lead to critical delays in the administration of essential care (Wallis *et al*., 2015).

Another important challenge is the lack of adequate and continuous training of healthcare professionals and rescuers in advanced resuscitation techniques and drowning management. Studies show that bystander-performed cardiopulmonary resuscitation (CPR) is effective, but often first responders may not be adequately trained and updated on best practices for CPR and other critical interventions. The lack of training can result in an inadequate response during the crucial first minutes after drowning, reducing survival chances and increasing the risk of neurological sequelae (Leavy *et al*., 2023; Sampaio *et al*., 2022).

Additionally, integrating new technologies and emerging treatments into drowning management faces significant barriers. Although continuous monitoring technologies and artificial intelligence have the potential to improve early detection of clinical deterioration, implementing these systems can be complex and expensive. The lack of adequate infrastructure and financial resources in many areas, especially in low-income regions, prevents the widespread adoption of these innovations, limiting potential benefits for patients (Sampaio *et al*., 2022).

To overcome these challenges, several strategies can be adopted. Implementing continuous training and refresher programs for healthcare professionals and rescuers is essential to ensure they are up to date with best practices and advanced resuscitation techniques. Additionally, creating standardized protocols that can be quickly adapted to the specific circumstances of each drowning incident can improve the initial response and treatment outcomes. Collaboration between governments, health institutions, and communities to fund and implement emerging technologies, as well as promoting awareness campaigns on the importance of drowning prevention and first aid training, is crucial to improving the effectiveness of drowning treatment (Leavy *et al*., 2023; Sampaio *et al*., 2022).

Although it is a frequent cause of death, drowning often does not result in hospitalization and is frequently underreported. This represents a significant challenge due to the scarcity of evidence, limited investigation, lack of data to guide the effective implementation of its treatment - especially concerning the duration of care and the need for hospital or intensive care unit (ICU) admission. Even less severe incidents should be reported to improve the availability of data and information that can benefit the quality of subsequent studies (Thom *et al*., 2021; Cibulski *et al*., 2023).

PREVENTION

The American Academy of Pediatrics advises that all children over 4 years old, who do not have motor development delays, receive swimming lessons. For children under 4 years old, it is not recommended due to the association with increased respiratory infections and life risk. However, it is important to remember that water skills alone do not prevent drownings, making measures such as pool fences and constant adult supervision indispensable. Proper child supervision is essential to prevent submersion accidents and should be complemented by community strategies (Batista *et al*., 2023; Capela *et al*., 2023).

In a study conducted by Capela *et al*. (2023), only 12% of reported incidents had a lifeguard present, which can largely be attributed to accidents occurring in private pools in condominiums, hotels, or private residences. To address this issue, preventive measures can be adopted, such as installing barriers to limit access to water, proper use of flotation devices for children (such as armbands and life jackets), implementing swimming lessons and water safety education in school curricula, teaching safe practices in aquatic environments, training residents and tourists in self-rescue techniques, and providing basic life support (BLS) to the general community.

In primary care, the family health team plays a role in risk detection through home visits, paying individual attention to each family and thus proposing safety measures to prevent accidents involving children in domestic environments, as these accidents are often associated with death. Another measure is community education, as studies have shown that mothers lack adequate knowledge on how to prevent this type of accident (Sampaio *et al*., 2022).

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