**Canine Drowning**

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**ABSTRACT:** Drowning is potentially fatal. Physiologic responses to aspiration of water differ according to whether the water is salt or fresh; whether these responses are significant depends on the volume of fluid aspirated. Resuscitation efforts should be started at the scene of the accident. Oxygen therapy is essential. Many patients require continuous positive airway pressure or positive end-expiratory pressure to reverse hypoxemia. Physiologic responses induced by ice-water submersion can be protective during the initial insult. The prognosis for submersion injuries is guarded and is influenced by several variables.

**Drowning** is defined as “the process of experiencing respiratory impairment from submersion or immersion in liquid.” The terms near-drowning and drowning were previously used to classify outcomes with regard to survival. However, these terms have been replaced with death, morbidity, and no morbidity following a drowning episode. In 2004, drowning was the second most common cause of accidental death in children younger than 14 years in the United States, with approximately five times as many children of this age sustaining morbidity from drowning.

It was previously believed that 85% to 90% of humans who drown experience wet drowning, in which a large volume of water is aspirated, and that 10% to 15% experience dry drowning, in which little or no water is aspirated but severe laryngospasm causes severe hypoxemia and eventual death. A more recent study, however, found that less than 2% of human deaths from drowning were “dry.” It is now presumed that in these cases, death occurred before the person entered the water or was due to a sudden cessation of circulation without aspiration of water. Active aspiration is required for water to enter the lungs. A conscious, submerged person usually aspirates water as he or she struggles in panic, which is associated with massive catecholamine release. Conversely, when a person loses consciousness before submersion/immersion (e.g., as a result of seizure), he or she quickly sinks, and there may be no catecholamine release. The terms dry drowning and wet drowning are no longer used.

Most of the initial studies on the pathophysiology of submersion/immersion injuries and the treatments for morbidity were conducted in dogs. Although the prevalence of drowning in dogs does not reach that in children, there are numerous unpublished reports of submersion/immersion injuries in dogs. Canine drowning has been associated with falling into water, swimming accidents, intentional immersion, seizures near water, and falling through ice. This article reviews the human literature based on the canine model, describes the pathophysiology of drowning, and presents the treatment and prognosis for the associated morbidity.
PATHOPHYSIOLOGY

Initial Injury

The earliest studies in dogs investigated the pathophysiology of freshwater versus saltwater drowning. Although drowning in either type of water can cause severe, potentially fatal hypoxemia, differences in the volume and composition of the fluid aspirated induce distinct physiologic responses. There is no evidence that chlorinated water has any effect on the pathophysiology or outcome.\(^9\)\(^{-12}\)

The presence of liquid in the oropharynx or larynx usually triggers a vagally mediated laryngospasm,\(^1\)\(^{-14}\) followed by reflex vasoconstriction in the lungs and immediate pulmonary hypertension.\(^13\) Freshwater, because its tonicity is lower than that of the body’s extracellular fluid, is rapidly absorbed from the alveoli through the alveolar–capillary basement membrane into the intravascular space.\(^15\) Blood volume and extracellular electrolyte concentrations immediately change secondary to a dilutional effect; hyponatremia and hypervolemia have consistently been observed moments after aspiration of a significant quantity of freshwater.\(^9\)\(^{,13,15-18}\) The hypotonicity of freshwater can also cause intravascular hemolysis with resultant hyperkalemia, hemoglobinemia, and hemoglobinuria.\(^4\)\(^{,15}\) The hematocrit can increase, presumably from swelling of erythrocytes.\(^9\)\(^{,15,19}\) However, unless the volume of freshwater aspirated is large (>22 ml/kg), these hematologic changes are rarely clinically significant.\(^9\)\(^{,15}\) In fact, by the time patients that have aspirated freshwater present to a hospital, hypervolemia has often given way to hypovolemia due to redistribution of fluids and pulmonary edema,\(^20\) and electrolyte concentrations are within normal ranges.\(^9\)\(^{,15}\)

In contrast to freshwater, salt water has a higher tonicity than the body’s extracellular fluid and thus has opposite effects. Salt water draws fluid from the intravascular space through the alveolar–capillary basement membrane into the alveolar space.\(^21\) Hypovolemia,\(^21\) a transient increase in plasma concentration of extracellular electrolytes,\(^13\)\(^{,16,21}\) and increased pulmonary fluid volumes result.\(^13\)\(^{,16,21}\)

In addition to their differences in tonicity, freshwater and salt water have different effects on the chemical properties of pulmonary surfactant,\(^12\) a hydrophobic–hydrophilic material produced by type II pneumocytes (specialized cells in the alveoli). Normally, the alveoli are lined with surfactant, which, by decreasing the surface tension of water, prevents their collapse during lung deflation and promotes lung compliance, or ease of lung inflation or expansion. Freshwater interferes with the ionic composition of surfactant, thereby altering its surface tension properties.\(^12\) The alveoli readily collapse, and right-to-left intrapulmonary shunting, in which blood flows from the right side of the circulation to the left side without ever coming into contact with a functional gas exchange unit, occurs.\(^10\) The lungs also become less compliant. Conversely, salt water washes out some surfactant but leaves the remaining surfactant intact without changing its surface tension properties.\(^12\) Because hypertonic salt water pulls fluid into the alveoli, an intrapulmonary shunt again results. The alveoli are perfused but, because they are filled with fluid, ventilation does not occur.\(^10\)

**Lung Damage**

Both types of fluid directly damage the type I and type II pneumocytes of the alveolar epithelium and the pulmonary capillary endothelial cells, causing inflammation, transudation of protein-rich fluid into the alveolar space, and interstitial and alveolar edema.\(^22\) The mechanical barrier between the environment and the patient is disrupted, increasing susceptibility to infection through bacterial translocation.\(^23\) Normal epithelial fluid and ion transport cannot occur, and the production of surfactant is altered.\(^24\) The alveolar–capillary basement membrane is exposed, leading to further migration and activation of neutrophils and macrophages and increased inflammatory cytokine production.\(^24\) Perfusion of the alveoli continues without ventilation, increasing the shunt fraction. The resultant hypoxemia is unresponsive to increased oxygen content of inspired air due to the totally obstructed alveoli or to shunting. The alveoli collapse because of the loss of surfactant, and lung compliance is decreased. This cascade of events is referred to as acute respiratory distress syndrome (ARDS).\(^24\)

**Hypoxemia and Acidosis**

Right-to-left intrapulmonary shunting, decreased pulmonary compliance, and ARDS cause a rapid decrease in arterial oxygen tension\(^10\); the patient may also be unable to

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**Cardiopulmonary efforts, including external cardiac massage and mouth-to-nose ventilation, should be started at the scene of the accident.**
expire carbon dioxide, causing hypercapnia.\textsuperscript{4,25} Retrospective studies found that humans who drowned in freshwater or salt water were consistently hypoxemic and acidotic.\textsuperscript{4,9,10,15} Metabolic acidosis in these patients is secondary to hypoxemia and lactic acidosis.\textsuperscript{24} By the time the patient arrives at the hospital, resuscitation efforts have usually been started and ventilation has been improved. Therefore, hypercapnia and respiratory acidosis are not usually evident on blood gas measurements, but persistent hypoxemia is documented and requires additional therapy.\textsuperscript{9,11,23}

\textbf{Hemodynamic Effects}

The hemodynamic effects of drowning include decreased cardiac output, increased pulmonary capillary wedge pressure (a reflection of left atrial pressure), and increased pulmonary vascular resistance, all of which occur secondary to hypoxia.\textsuperscript{11,13} Hypoxemia, hypotension, and hemoglobinuria can lead to renal damage as well.\textsuperscript{17} Ventricular fibrillation may cause death.\textsuperscript{15}

\textbf{Complications}

Severe complications can result when the aspirated water is grossly contaminated with particulate matter or bacteria. If the material is an appropriate size, it may obstruct the smaller bronchi and bronchioles.\textsuperscript{2} Severe pulmonary infection may also develop in dogs. In humans, airway obstruction has generally not been found to interfere with artificial ventilation, and severe infection rarely develops.\textsuperscript{26}

\textbf{ON-SITE RESUSCITATION}

Cardiopulmonary resuscitation efforts should be started at the scene of the accident. Mouth-to-nose resuscitation should be commenced if the animal is apneic.\textsuperscript{7} External cardiac massage should be performed if a heartbeat is not detected.\textsuperscript{7} The drowned animal can quickly be positioned to promote gravitational drainage of fluid from the lungs; however, the rescuer should not spend too much time on this effort because drainage has not been found to affect outcome.\textsuperscript{7,27} Freshwater is absorbed quickly, so gravitational drainage may be more logical in salt water submersion injuries.\textsuperscript{7}

Previous recommendations in humans included the Heimlich maneuver to remove water from the lungs.\textsuperscript{28} It is now known that most humans who drown also swallow substantial quantities of fluid.\textsuperscript{7,29} The Heimlich
The maneuver is currently only recommended when the airway is blocked with solid material because abdominal thrusts can cause vomiting with aspiration of gastric contents, which compounds the damage to the lungs and causes more severe pulmonary edema. The Heimlich maneuver also delays the application of effective artificial ventilation, compounding hypoxia. Approximately 24% of humans who drown vomit, so in humans, the airway should be protected by appropriate positioning. After resuscitation efforts, animals that have drowned should be wrapped in a warm blanket (if immediately available) and taken directly to a veterinary hospital.

**DIAGNOSIS**

In animals, the diagnosis of drowning is usually made based on the patient’s history at presentation. The owner should be asked about the submersion/immersion injury and the events preceding it. The interview should take as little time as possible and should include questions about the type of water in which the animal drowned (salt water or freshwater), the length of time the animal was under water, prior episodes of seizures or syncope, and the possibility of accidental drug ingestion. A detailed description of the resuscitation should be recorded and should include information about the animal’s level of consciousness, heart rate, respiratory rate, and temperature at rescue.

A thorough physical examination should be performed. Measurement of arterial blood gas is imperative; thoracic radiography, although important, is less critical. Radiographic changes may lag behind clinical signs. Radiographically, an alveolar pattern is most prominent in the early stages after drowning, although strong interstitial and bronchial components can also be present. Hyperinflation of the lungs may be seen because of increased respiratory efforts by the patient. If initial treatment efforts are successful and ARDS does not develop, the alveolar pattern will resolve, leaving a mixed interstitial-bronchial pattern, and radiographic evidence of lung pathology will dissipate within 7 to 10 days of the drowning incident. However, if the pulmonary disease worsens despite initial treatment, the alveolar pattern will become more severe, possibly indicating pneumonia.

**TREATMENT**

**Oxygen Therapy**

When the patient arrives at the hospital, an intravenous catheter should be placed for vascular access. Electrocardiography should be monitored and cardiac arrhythmias treated appropriately. Oxygen therapy is of utmost importance. In humans, mechanical ventilation is started if the patient cannot maintain a PaO\(_2\) of more than 90 mm Hg despite a supplemental fraction of inspired oxygen concentration (FiO\(_2\)) of 50% or if the patient is apneic. Criteria for artificial respiration in dogs are a PaO\(_2\) of less than 60 mm Hg with an FiO\(_2\) greater than 50% or a PaO\(_2\) of less than 40 mm Hg at any FiO\(_2\).

The most effective treatment in reversing hypoxemia after a submersion injury is continuous positive airway pressure (CPAP) or positive end-expiratory pressure (PEEP). CPAP maintains positive pressure in the airways throughout respiration, and PEEP maintains positive airway pressure in the airways during expiration and between breaths. The purpose of PEEP and CPAP is to keep the alveoli open at the end of expiration to increase the functional residual capacity—the volume of gas in the lungs at the end of normal expiration—and to decrease intrapulmonary shunting. Otherwise, the alveoli collapse easily because of high surface tension due to surfactant loss (after aspiration of all types of fluid) or damage (after aspiration of freshwater). Keeping the alveoli patent and ventilated and increasing functional residual capacity decrease airway resistance and improve lung compliance. Optimal PEEP or CPAP decreases the work of breathing, improves ventilation-perfusion abnormalities, and minimizes intrapulmonary shunting. Care should be taken to avoid excessive CPAP or PEEP because it can impede venous return in an already volume-compromised patient and can cause barotrauma by overdistending healthy alveoli.

The choice of which ventilation mode to use may depend on the type of fluid aspirated. Either CPAP (with spontaneous respiration) or PEEP can effectively improve hypoxemia when salt water has been aspirated. In cases of freshwater drowning, PEEP with controlled mechanical ventilation is usually needed to improve hypoxemia; CPAP with spontaneous respira-
tion is frequently inadequate. This is likely due to the higher surface tension in the alveoli secondary to surfactant damage incurred by freshwater.

In humans and animals being treated for drowning, it is recommended that PEEP be started at 5 cm H₂O, then increased by 2 to 3 cm H₂O until the PaO₂/FiO₂ ratio is at least 300 or until the FiO₂ can be decreased to less than 60% while maintaining adequate arterial oxygen tension. The FiO₂ should be reduced to less than 60% as soon as possible to avoid oxygen toxicity. An FiO₂ of 1.0 for 48 to 72 hours has been shown to cause death in animals. Supplemental oxygen should be continued with or without CPAP or PEEP until the arterial oxygen tension is adequate. Although it takes approximately 20 hours to regenerate surfactant, in one study, it took 3 to 7 days for PaO₂ to return to normal in dogs that survived freshwater drowning.

As previously mentioned, many dogs that drown are hypovolemic secondary to pulmonary edema. Dogs that are being mechanically ventilated also may have decreased venous return. Intravenous lactated Ringer’s solution was found to improve cardiovascular parameters in dogs that aspirated freshwater and were ventilated mechanically with PEEP. Mean arterial pressure, cardiac output, central venous pressure, pulmonary capillary wedge pressure, and oxygen delivery increased while systemic vascular resistance, pulmonary vascular resistance, and arteriovenous oxygen content difference decreased. Intrapulmonary shunting was not affected by appropriate amounts of intravenous fluids. Most drowning patients have metabolic acidosis, and in humans it is recommended that metabolic acidosis be treated if the pH is less than 7.1 to prevent further cardiovascular compromise. Electrolytes, blood urea nitrogen, creatinine, glucose, and urine output should also be monitored.

**Other Therapies**

The main therapeutic goal after resuscitation in humans is the prevention of hypoxic neurologic injury. During the 1980s, controversy arose regarding the method of treating humans who presented to the hospital with neurologic abnormalities after drowning. One author proposed categorizing patients who had drowned based on their level of consciousness on presentation to the hospital and instituting “cerebral salvage” therapy in them. He treated aggressively with continuous dehydration with furosemide, controlled hyperventilation to minimize intracranial pressure, hypothermia to decrease cerebral oxygen requirements, barbiturate coma to decrease intracranial pressure and for a “beneficial effect on neurons,” and continuous muscle paralysis to prevent movement that might increase intracranial pressure. Although initial publications showed an increase in survival and a decrease in long-term neurologic deficits, subsequent studies found some of the therapeutic methods to be detrimental. Intracranial pressure was elevated in patients with ischemic cerebral injury secondary to prolonged hypotension but not in those with hypoxic cerebral injury, suggesting that dehydration is contraindicated. Hypothermia decreased the number of circulating neutrophils and their release from the bone marrow and was associated with the development of sepsis. It did not increase the survival rate. Although barbiturates may control intracranial pressure, their use did not improve neurologic outcome. Treatment in humans is aimed at maintaining cerebral perfusion pressure and adequate oxygenation to prevent further damage to vital organs; similar recommendations likely apply to dogs.

There is no evidence that steroids improve the PaO₂, the degree of intrapulmonary shunting, or the survival rate in dogs that aspirate freshwater. Pulmonary pathology was similar between dogs that did and did not receive steroids after aspiration of acidic fluid and resultant aspiration pneumonitis. Steroids have been shown to interfere with the granulomatous response in rabbits after aspiration of gastric contents; therefore, the administration of steroids to drowned animals is not recommended.

Prophylactic antibiotics have not been found to affect survival in drowned animals and have been found to

Although treatment with pentoxifylline may be beneficial in reducing indirect lung injury, there is no evidence that steroid or prophylactic antibiotic therapy improves the survival rate in drowned animals.
select for more resistant organisms if infection does develop.⁴³ A better approach is to monitor for signs of infection. If the patient is febrile or has leukocytosis, or if cytology of tracheal aspirates shows evidence of bacterial infiltration, antibiotic therapy should be started while awaiting results of bacterial cultures and sensitivities.²⁶

A recent study⁴⁶ in Japan found that a continuous-rate infusion of pentoxifylline reduced indirect lung injury (lung injury secondary to ARDS) in dogs after aspiration of freshwater. Pentoxifylline is a methylxanthine derivative and a nonspecific phosphodiesterase inhibitor. It was found to decrease the expression of intercellular adhesion molecule-1 (ICAM-1) mRNA. ICAM-1 is an immunoglobulin that is expressed on endothelial cells and neutrophils and is involved in the migration of neutrophils into lung tissue. Histology of lung tissue from dogs that received pentoxifylline showed a marked decrease in neutrophil infiltration. Clinical studies showing beneficial effects of pentoxifylline are necessary before this treatment can be recommended.

β₂ Agonists and methylxanthines, which are short-acting bronchodilators, may be helpful in alleviating hypoxia when bronchospasm is suspected.

**SUBMERSION IN ICE WATER**

Although hypothermia is contraindicated as a therapeutic method, hypothermia during drowning appears to be protective. The rapid drop in core body temperature decreases the metabolic oxygen requirements of the brain.¹⁶ A “diving reflex” has been identified in seals, dogs, and humans, in which the sensation of cold water on the face causes apnea and bradycardia and vasoconstriction causes shunting of blood to the heart and brain to conserve oxygen.⁴⁷ This can allow a hypoxic animal to survive for longer periods of time with preservation of brain function. There are reports⁴⁸,⁴⁹ of humans who were found without a pulse and in ventricular fibrillation or cardiac asystole after ice water submersion for as long as 66 minutes and survived, and experimental studies in dogs have demonstrated successful resuscitation after the dogs appeared clinically dead.⁵⁰ These isolated reports were likely publicized because the person or animal survived. More often, anoxia or fatal arrhythmia leads to death.²⁶,⁵⁰

When a dog is treated for drowning, its body temperature should be noted before resuscitation efforts are discontinued. The patient should not be pronounced clinically dead until it is normothermic and resuscitation efforts have been unsuccessful. Hypothermic patients should be handled carefully because the cold, brady-cardiac heart is susceptible to fibrillation.⁷,⁵⁰ If there is true cardiopulmonary arrest, cardiopulmonary resuscitation should be continued, although hypothermic patients are relatively resistant to pharmacologic and electrostimulatory therapy.⁷ In humans, defibrillation by electric shock is recommended if the patient presents in ventricular fibrillation with a core body temperature greater than 85°F (29.4°C).⁷ The patient should be rewarmed, although it is not known whether the rapidity or method of warming affects survival.⁷,¹⁶ In humans, use of warm water baths; warmed intravenous fluids, blankets, and heating pads; and warm orogastric lavage to aggressively re warm the patient is recommended when the core body temperature is less than 85.1°F (29.5°C).⁷ Heating pads should be used with caution in dogs because they can cause skin burns. When the patient’s core temperature is between 85.1°F and 89.6°F (29.5°C and 32°C), slow, active rewarming with heating pads, warmed intravenous fluids, and warmed, humidified oxygen should be instituted.² When the rectal temperature is greater than 89.6°F, rewarming at a rate of 1°C per hour should be sufficient.⁷ Because shivering increases metabolic oxygen requirements, efforts should be made to avoid producing shivering until circulation can adequately deliver oxygen to the tissue.¹⁶

**PROGNOSIS**

The survival rate after fluid aspiration is inversely proportional to the volume of water aspirated.²¹ A recent review of 15 dogs and one cat that drowned in freshwater found a mortality rate of 37.5%, with animals in respiratory failure having a worse prognosis.⁸ In humans, retrospective data have been analyzed to identify prognostic indicators, but no single factor has been found to be completely reliable. Factors that have been suggested to have a negative influence on survival and brain function include prolonged submersion;² a delay in starting resuscitation;² a blood pH of 7.1 or less;² fixed, dilated pupils on presentation;¹¹ and drowning in warm water (temperature >68°F [20°C]).⁵¹ Spontaneous respiration⁵¹ and hypothermia (<91.4°F [33°C]) with a detectable heartbeat on presentation²² have been associated with survival and preservation of neurologic function. Prognostic scoring systems using the Glasgow Coma Scale⁵³ to assess level of consciousness on arrival to the hospital have been used, but, again, results have not been consistent.

Some human patients present conscious and eupneic but develop cerebral edema²,⁵² or ARDS⁴⁵ within 12 hours. It is recommended that all human patients, even those that
appear stable, be hospitalized for at least 24 hours for monitoring for late neurologic or pulmonary sequelae. A retrospective study of 41 dogs and cats that were managed with mechanical ventilation found an overall survival rate of 39%; of the animals that were ventilated because of primary pulmonary parenchymal disease, only 20% (four of 20) survived. A similar study found that 20% of animals with hypoxemic ventilatory failure were weaned from mechanical ventilation and 11% were discharged. The use of PEEP was significantly associated with the development of pneumothorax, which negatively affected survival.

**PREVENTION**

The number of submersion accidents can be decreased by increasing owner awareness of drowning risks. Dogs can drown in swimming pools, oceans, lakes, ponds, toilets, bathtubs, and water bowls. A recent study of freshwater drowning in small animals found the distribution of drowning in man-made and natural bodies of water to be approximately equal; swimming pools were the most common man-made drowning location. Dogs that are very young or elderly may not have the strength to swim or to get out of the water. Dogs with disorders such as syncope or seizures should be either kept away from water or carefully observed while swimming. Likewise, blind or debilitated dogs should be allowed near water only when closely supervised. A barrier might be effective in preventing an unsupervised dog from entering a swimming pool or other body of water. Life jackets are also available for dogs. Owner education and training in canine cardiopulmonary resuscitation might also prevent fatalities.

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**REFERENCES**


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**Compendium**

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1. Which condition does not result immediately after aspiration of a large volume of freshwater?
   a. hypernatremia   b. hemoglobinemia
   c. hypervolemia   d. hyperkalemia

2. Which condition does not contribute to intrapulmonary shunting after aspiration of salt water?
   a. pulmonary edema   b. loss of surfactant
   c. laryngospasm   d. ARDS

3. Which condition is not a feature of ARDS?
   a. increased susceptibility to infection
   b. preservation of normal epithelial fluid and ion transport
   c. pulmonary edema
   d. altered production of surfactant

4. On-site resuscitation efforts can consist of all of the following except
   a. mouth-to-nose resuscitation.
   b. external cardiac massage.
   c. gravitational positioning.
   d. the Heimlich maneuver.

5. Which is the most important diagnostic test/tool when a drowned animal presents to the hospital?
   a. thoracic radiography
   b. arterial blood gas measurement
   c. tracheal fluid cytology
   d. pulse oximetry

6. Which is not a purpose of PEEP or CPAP?
   a. to decrease airway resistance
   b. increase the functional residual capacity of the lungs
   c. to decrease intrapulmonary shunting
   d. increase venous return

7. Which therapy should be used in the treatment of drowned animals?
   a. oxygen therapy
   b. Vasoconstriction
   c. prophylactic antibiotics
   d. steroids

8. _________ is not part of the diving reflex.
   a. Apnea
   b. Hypothermia
   c. Tachycardia
   d. Vasoconstriction
   e. Bradycardia

9. Which statement regarding ice-water submersion injuries is true?
   a. The heart is susceptible to ventricular fibrillation.
   b. Hypothermia increases the brain’s metabolic oxygen requirements.
   c. Hypothermic patients should be pronounced dead if a heartbeat is not detected at presentation to the hospital.
   d. The patient should not be rewarmed because hypothermia should be used as a treatment.

10. Which statement regarding prevention of submersion injuries is false?
    a. Dogs with underlying disorders such as seizures or syncope should not be allowed in the water unsupervised.
    b. Drowning can only occur in a large body of water, such as a pool, lake, or ocean.
    c. Geriatric dogs might not have the strength to get out of the water.
    d. Life jackets can be helpful in preventing fatalities from drowning.