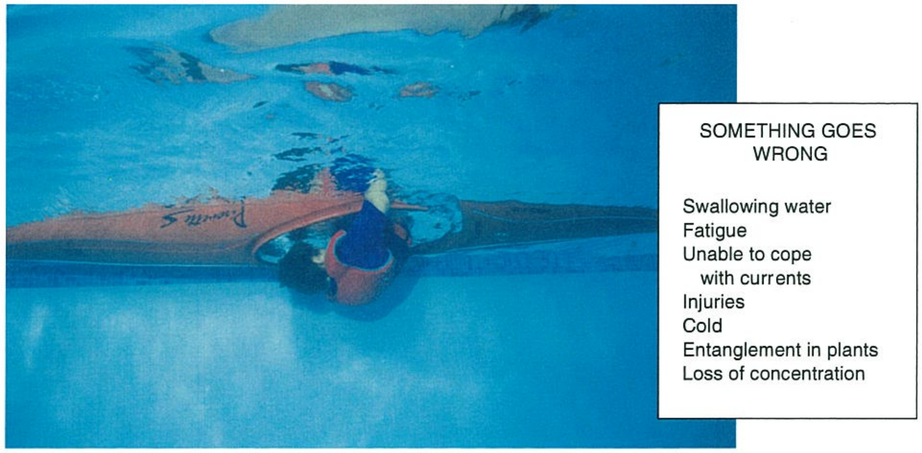

Figure 29-4 The aspiration of water and other events can lead to dire, even fatal outcomes.

Table 29-1 Events in the Pathophysiology of Drowning

- Panic
- Gasping
- Possible aspiration of liquid (minor)
- Laryngospasm
- Hypoxia
- Loss of consciousness
- Myocardial irritability (electrical disturbances)
- Cardiac arrest
- Relaxation of airway muscles
- Fluid aspiration (massive)

laryngospasm spasm of the vocal cords that prevents air movement through the respiratory tract.

mammalian diving reflex a reflexive response to diving in many mammals that is characterized by physiological changes that decrease oxygen consumption (including slowed heart rate and decreased blood flow to the abdominal organs and muscles) until breathing resumes.

Depending on how much water enters the lungs, drowning may be either "dry" or "wet." Dry drowning is more common than wet drowning and involves aspiration of a small amount of fluid and violent **laryngospasm**, which tightly seals the airway. In this form of drowning, very little fluid actually enters the lungs. In wet drowning, by contrast, either laryngospasm is minor or the airway muscles quickly relax, allowing liquid and any material it contains to flood into the lungs. Dry drowning usually precedes wet drowning, although wet drowning may occur alone.

As soon as the body is immersed or submerged in extremely cold water, peripheral blood vessels tightly constrict, which shunts warm blood away from the body surface and to the heart and brain. At the same time, the body's metabolic and heart rates slow significantly, reducing oxygen demand and conserving oxygen. This very effective protective response, known as the "**mammalian diving reflex**," helps to protect the heart and brain for a period of time. Some patients have survived under cold water for more than 60 minutes due to this reflex. The mammalian diving reflex is most prominent in young children and, for reasons that are not clear, appears to diminish as a person gets older.

As described in Chapter 28, Altitude-Related Emergencies, changes in barometric pressure affect the way gases within the body react. The same principles hold true when the body is under water, especially at a depth of 33 feet, where the pressure of the water is 2 atmospheres (ATM): 1 ATM from the air plus 1 ATM from the water.

What Is an Atmosphere?

NOTE

One atmosphere equals the pressure of air at sea level (14.7 pounds per square inch). Put another way, if you took all the air above one square inch of the earth's surface at sea level and weighed it all the way into space, that air would weigh 14.7 pounds. Because water is more dense than air, it takes one inch square column of water only 33 feet high to equal one atmosphere.

Fully understanding how diving injuries occur requires a basic understanding of three laws that affect gases: Boyle's law, Henry's law, and Dalton's law.

29-4 Describe the following gas laws:

- Boyle's law
- Henry's law
- Dalton's law

Boyle's Law

Briefly, Boyle's law states that at a constant temperature, the volume of a gas is inversely proportional to the pressure exerted by that gas. In other words, as one descends in a body of water and the water pressure increases, the pressure inside the chest cavity and the lungs increases, which causes the volume of gas within the lungs to decrease. Thus, if you have 6 liters of air in your lungs and you dive to 33 feet (2 atmospheres of water pressure and 1 atmosphere of air pressure for a total of 3 atmospheres), the volume of air in your lungs is reduced (compressed) by half, to 3 liters. Conversely, when pressure decreases, the volume of a gas increases (expands).

When you ascend from a depth of 33 feet to the surface, the volume of gas within your lungs will attempt to increase. Because the total volume of the lungs is limited by the size of the chest, the resulting increase in pressure (as the gas tries to expand) within the lungs can rupture them. The same is true for any other air-filled body cavity or body structure.

Boyle's Law

NOTE

At a constant temperature, the volume of a gas is inversely proportional to the absolute pressure of the gas. Translation: when pressure decreases, the volume of a gas increases, and vice versa.

Henry's Law

Henry's law states that at a given temperature, the amount of gas that will dissolve in a liquid is directly proportional to the **partial pressure** of the gas.

partial pressure the pressure of a single gas within a mixture of gases; the partial pressure of each gas in a mixture of gases is equal to the pressure that gas would exert if it occupied the same volume alone at the same temperature.

This means that a gas such as nitrogen will remain dissolved in the blood so long as the partial pressure remains constant. If the external pressure suddenly decreases, bubbles may form. Should bubbles form within the bloodstream, they can lodge in a vessel and obstruct blood flow, resulting in a variety of problems.

What Is Partial Pressure?

NOTE

In a mixture of gases, each gas is responsible for part of the total pressure of the mixture. Put another way, the partial pressure of each gas in a mixture of gases is equal to the pressure that gas would exert if it alone occupied the same volume at the same temperature.

Dalton's Law

Dalton's law states that the pressure of a mixture of gases is the sum of the partial pressures of all the gases in that mixture. At sea level, air pressure is one atmosphere or 14.7 pounds per square inch (psi). If the gas at the water's surface is a mixture containing just two gases, 20 percent oxygen and 80 percent nitrogen (which is close to what is in air), then the pressure exerted by the oxygen is 0.20×14.7 psi or 2.94 psi, and the pressure exerted by the nitrogen is 0.80×14.7 or 11.76 psi. The pressure at a depth of 66 feet is 3 atmospheres, or 44.1 psi. In the same mixture of gases, the pressure from oxygen is 0.20×44.1, or 8.82 psi, whereas the pressure from nitrogen is 0.80×44.1, or 35.28 psi. So as one goes deeper under water, the pressure from nitrogen is greatly increased.

Why Do Carbonated Beverages Bubble?

NOTE

When you open a bottle of carbonated beverage, you reduce the pressure over the surface of the liquid, so bubbles come out of the liquid and go into the air above the liquid.

Henry's Law

NOTE

At a given temperature, the amount of gas that will dissolve in a liquid is directly proportional to the partial pressure of that gas. Translation: at higher pressures, more gas will dissolve in a liquid; when the pressure decreases, the gas will come out of the liquid and form bubbles.

Dalton's Law

NOTE

The pressure of a gas mixture is the sum of the partial pressures of all the gases in the mixture. Translation: the overall pressure of a gas is made up of the pressure of each individual gas, added together.

and streams. Submersion in warm or hot water (in bath tubs or hot tubs) can cause vasodilation and quickly lead to distributive shock.

Water salinity affects the movement of water within the body. Because fresh water has a lower **tonicity** (a lower salt concentration) than alveolar fluid, aspirated water moves into the lung tissue and then into the bloodstream, causing low blood sodium (hyponatremia) and increased blood volume (hypervolemia). Note, however, that an adult male would have to aspirate more than 7 liters of water for these effects to occur. Wet drowning will normally occur first with the aspiration of 7 liters of water.

tonicity a property of solutions that relates to the concentration of solutes (such as salt) it contains, and how the water in a solution moves across a cell membrane; water in a solution crosses a cell membrane from the side that has the lower tonicity (a hypotonic solution) to the side that has the higher tonicity (a hypertonic solution); pure water is hypotonic to the solution within cells because that solution contains salts.

Conversely, salt water has a higher tonicity than the water in body tissues. Thus, aspiration of salt water causes fluid to leave the bloodstream and enter the lungs, causing hypovolemia and hypernatremia. Again, large volumes of salt water must be aspirated for significant fluid shifts to occur. The finding that only 15 percent of drowning victims have electrolyte abnormalities suggests that massive fluid shifts are uncommon. Because few people drown from large volumes of aspirated water, the salinity of the water is less important than the temperature of it.

Water, especially moving water, contains millions of suspended particles per liter that may be aspirated, causing a host of problems depending on the particles' sizes and composition. Dirt, rocks, and other inorganic debris may become lodged anywhere along the air passageways, reducing airflow and oxygenation. Pathogens such as bacteria or parasites such as *Giardia* may be aspirated deep into the delicate pulmonary tissues, resulting in local or systemic infections. Organic matter such as algae, seaweed, and other aquatic life can also block or damage the lower airways.

Barotrauma

29-5 List three types of barotrauma and indicate their causes.

Barotrauma is a form of trauma that is caused by the difference in the pressure within air-filled structures of the body (e.g., the lungs, intestines, and the middle ear) and the pressure of the external environment. Such pressure differences result from the expansion or compression of the gas within those body structures. If the pressure within the structure becomes too great, the structure can rupture; a reduction in pressure can create a vacuum, which also causes medical problems.

barotrauma trauma that is caused by differences in pressure between the body and the environment.

Barotrauma is a common disorder among divers and can occur during rapid descent or ascent. According to the Divers Alert Network (DAN), an international organization that provides information to divers and rescuers, approximately 1,000 cases of DCI (decompression illness) occur each year.

decompression sickness formation of nitrogen bubbles in tissues from a too-rapid ascent.

There are three basic types of dive injuries with which OEC Technicians should be familiar: decompression sickness, arterial gas embolism, and squeeze.

Decompression Sickness

Decompression sickness, also known as DCS or more commonly as "the bends," is a buildup of nitrogen bubbles within the body (Figure 29-9■). It occurs primarily in scuba divers who ascend too rapidly, but it may also occur if a diver travels to high altitude (by either plane or car) too quickly after diving. DCS results when dissolved nitrogen within the blood forms bubbles.

Figure 29-9 This patient has decompression sickness ("the bends") and has been placed in the recovery position while awaiting ambulance transport to a medical facility.

To illustrate this process, consider a bottle of carbonated soda. Dissolved within the liquid soda is carbon dioxide (CO_2), a gas that gives the liquid its characteristic "fizz." The CO_2 cannot be seen because it is under pressure. Once the bottle is opened, however, the pressure within the bottle is rapidly released, causing CO_2 bubbles to form. In a diver who has ascended from a depth, dissolved nitrogen in the blood forms bubbles as the pressure of