Drowning: Cause and Prevention

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INTRODUCTION

This article covers the fatality of submersion incidence caused by the lack of oxygen to the brain (**drowning**), and the survival from such episodes (**near-drowning**) through timely interventions. It excludes accidental fatalities in water caused by bodily injuries, biological hazards, natural disasters, and deaths from secondary infections or other complications. The authors emphasize the physiological basis of drowning, resuscitation procedures, management, and prevention of drowning.

Shallow water blackout[1] often leads to drowning and occurs when least expected. It should be noted, however, that not all drownings are caused by shallow water blackout. More importantly, the physiology of shallow water blackout is well-known and, therefore, preventable as emphasized in this article.

Whereas the probability of surviving cold water drowning is excellent even after a hopelessly long submersion, the same cannot be said of drowning in warm water. Neurological deficits inevitably follow submersions that exceed six minutes. Therefore, prompt and timely intervention is the key to reviving drowning victims in warm waters.

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[1] Dr. Edward Lanphier, of the University of Wisconsin-Madison, whose original investigations contributed to the understanding of gas exchange during breath-hold diving, called the authors' attention to the origin of the term shallow water blackout. According to Lanphier, the term was used during World War II by the British Navy in connection with the investigation of accidents using a closed-circuit oxygen-rebreathing unit in shallow water. In this article, however, the term **shallow water blackout** or **drowning** was adapted from common usage describing blackout in breath-hold diving. In breath-hold diving, blackout occurs mostly during the ascending phase of the dive and is, therefore, shallow water in nature.

DROWNING

Drowning is the third most common cause of accidental death for people of all ages in the United States and the second leading cause for children and young adults, according to a 1992 National Safety Council report. Children and young adults account for three-quarters of all drowning victims (Table 1). Drownings in the United States totaled 4,600 in 1991, even though the rate per 100,000 people decreased by 33% from the last decade (Figure 1). Freshwater drownings outnumbered saltwater drownings by a large margin, except in Hawaii (Table 2). Drownings in Hawaii occur at a rate similar to the rest of the nation (2.1/100,000 in 1990) but vary widely from year to year. For example, the rate was 1.9/100,000 in 1989 but increased to 3.7 in 1990, according to the State of Hawaii Department of Health Annual Report. The rate of drowning is surprisingly low in Hawaii considering the 750 miles of open coastline, the large number of swimming beaches, the high rate of swimming pool ownership, and the popularity of year-round ocean recreation for the state's 1.1 million residents and 7 million yearly visitors. This low rate possibly reflects the well established public education on water safety and the effective legislation on pool safety.

Hawaii statistics indicate that three out of four submersion accident victims survive to become ***near-drowning*** statistics. The estimated number of near-drowning victims, however, varies widely (two to 10 times the drowning death rate) because of the inclusion of a wide spectrum of incidences. The complete recovery of 19% to 24% of all drowning victims suggests the importance of resuscitation efforts. Unfortunately, clinical reports also show an extremely high rate of severe neurological sequelae (any remaining abnormal condition) (26% to 33%) in near-drowning cases.

PHYSIOLOGY

Normal Gas Exchange

During the course of normal breathing, fresh air comes in contact with blood that is returning to the lungs (venous blood) from the body's tissues. The dark, red venous blood turns into bright, red arterial blood after picking up oxygen and giving up carbon dioxide. While circulating throughout the body, the arterial blood loses oxygen, gains carbon dioxide, and returns again to the lungs for renewal. Used air is expelled by exhalation and the breathing cycle is repeated.

Drowning and Near-Drowning

If for some reason breathing stops (e.g., because of voluntary or involuntary holding of breath (**apnea**), airway obstruction (choking), or lack of air supply (as when trapped underwater), the blood returning to the lungs departs for tissues without a fresh supply of oxygen. The result is a diminished rate of oxygen delivery to tissues and a subsequent loss of consciousness within four to six minutes. Among the body's organs, the brain has the lowest tolerance to oxygen deprivation (**hypoxia**). As hypoxia progresses, the victim turns blue, gasps for air, but inhales water instead. Without prompt intervention, the victim will die.

The prospect of recovering from a freshwater drowning is better than that for saltwater. Although water in the lungs by itself does not necessarily result in death, hypoxia and metabolic disturbances following the inhalation of water can lead to a serious and immediate threat to life. Prompt reversal of hypoxia is the key to surviving a drowning with minimal afteraffects (**sequelae**). If the victim's heart has stopped, **CPR** should be administered immediately. The basic rule of rescue efforts has always been to follow the **ABC** sequence: clear the **airway**, restore **breathing** by artificial respiration (chest compressions or mouth-to-mouth resuscitation), and reinstate **circulation**.

TABLE 1. DROWNING BY AGE IN 1989

Age	Death	%
< 5	683	15
5-14	515	11
15-24	905	19
25-44	1,429	30
45-64	616	13
65-74	289	6
> 75	279	6
Total	4,716	100

Drownings in the U.S., National Safety Council, 1992. Three out of four drowning incidents occurred in age groups below 44 years old.

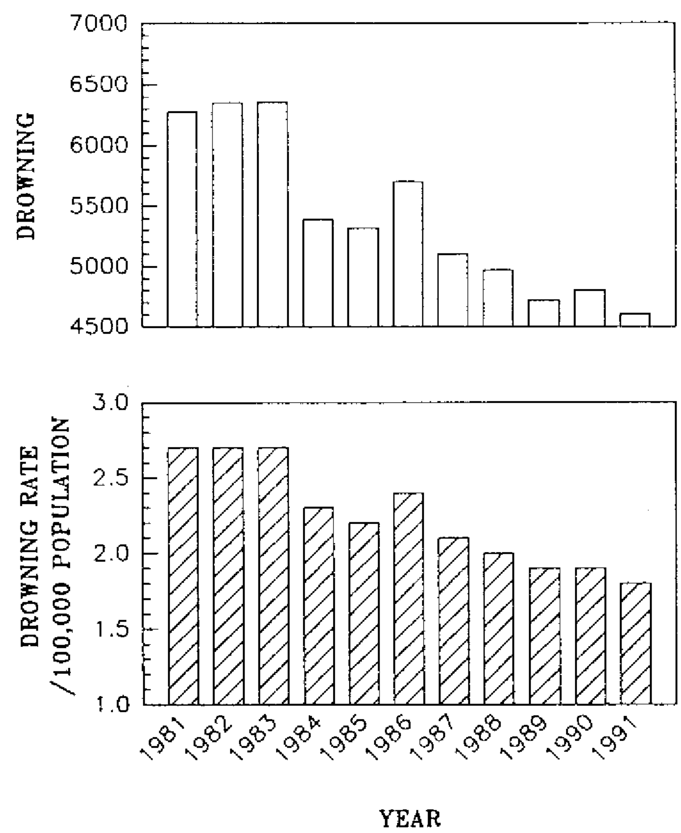

Figure 1. *Annual number of drowning deaths in the United States according to the National Safety Council 1992 report.*

TABLE 2. FRESHWATER AND SALTWATER DROWNING

Area	Fresh, %	Salt, %
Georgia (1981–83)[1]	96	4
Honolulu (1973–77)[2]	57	43
Los Angeles (1976–84)[3]	83	17
Maryland (1972)[4]	85	15
N. Carolina (1980–84)[5]	89	11
Virginia (1967–82)[6]	92	8

[1] From: *Morbidity and Mortality Weekly Report* 34:281, 1985
[2] From: *American Journal of Public Health* 69:450, 1979
[3] From: *Journal of American Medical Association* 260:380, 1988
[4] From: *American Journal of Public Health* 64:303, 1974
[5] From: *Morbidity and Mortality Weekly Report* 35:635, 1986
[6] From: *Pediatrics Clinics of North America* 32:113, 1985

Shallow Water Blackout

Shallow water blackout can occur in a normal course of recreation in water. Breath-hold and submergence lasts only a few seconds to one minute at the most. During apnea, the blood loses oxygen to the body, gains carbon dioxide, and increases in acidity. These chemical changes give a swimmer the urge to resume breathing, i.e., to return to the surface. In Figure 2, the solid circles and dashed lines show the changes of gas pressure in the lungs during a simple, out-of-water apnea in air, and the open circles and solid lines (panels B and C, and E and F) indicate the changes during a dive to a 10m depth. As the apnea continues, the urge to breathe becomes stronger because of the combined effects of the falling partial pressure of oxygen, the rising partial pressure of carbon dioxide, and the shrinking lung volume. Among these stimuli to breathe, the elevated PCO_2 is the strongest. While such an urge can be suppressed voluntarily to some degree, breathing must resume eventually, therefore, apnea is normally a self-terminating event. In contrast to the falling partial pressure of oxygen in simple breath-holding, the partial pressure of oxygen remains high throughout a 10m dive (Figure 2B, open circles and solid lines).

The amount of time a person can hold their breath can be prolonged by a variety of techniques. Among them, **hyperventilation** is the most effective. Hyperventilation, deep and rapid breathing for several seconds, moves air in and out of the lungs in excess of the body's need for oxygen. Hyperventilation does very little to increase the supply of oxygen, but drastically lowers carbon dioxide in the lungs and also in the arterial blood (Figure 2, E and F). Hyperventilation prolongs diving time because it takes longer for carbon dioxide to build up to the level normally causing the urge to resume breathing. The lowering of oxygen occurs at the same rate with or without hyperventilation. The lack of carbon dioxide stimulation and the elevated partial pressure of oxygen delays the swimmer's urge to surface, but the concentration of oxygen in the lungs continues to fall. After 60 seconds, despite the falling oxygen concentration, the partial pressure of oxygen is still above the hypoxic level (approximately 100 mmHg at 10m depth) and the swimmer perceives no urgency to surface. As the diver ascends, however, the ambient pressure falls and the partial pressure of oxygen decreases precipitously (Figure 2). Loss of consciousness may occur before reaching the surface when the partial pressure of oxygen falls below 30 mmHg.

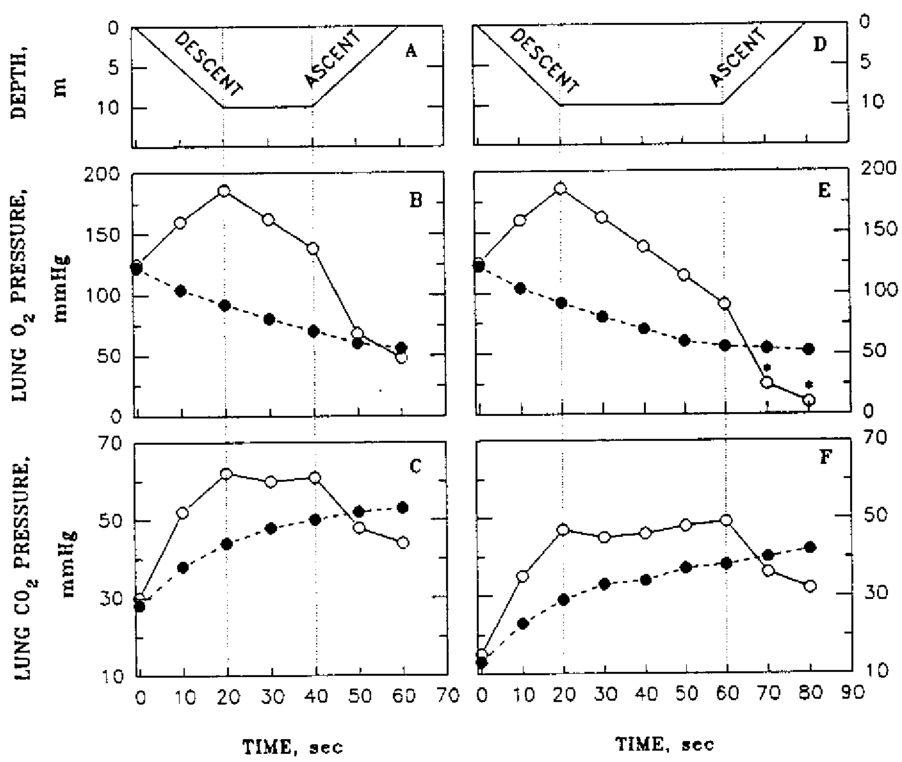

Figure 2. *Physiological basis of shallow water drowning. The left-hand panels show pressure changes of gases in the lung (actually alveolar gases) following a breath-hold in air (●) or descent to a simulated 10m depth (o) in the hyperbaric chamber. The right-hand panels indicate changes during a breath-hold after hyperventilating to lower the CO_2 pressure in the lung. Note that hyperventilation does not alter O_2 pressure significantly (usually signified as PO_2, and its unit is mm of mercury column height or mmHg) but lowered carbon dioxide drastically. Consequently, the breath-holding time is prolonged. On the ascent, PO_2 fell drastically (asterisks) causing hypoxia and blackout (based primarily on data of Lanphier and Rahn, 1963; and Hong and Lin's research conducted in the Department of Physiology, University of Hawaii (see suggested reading).*

The swimmer who blacks out in water becomes a drowning victim if not rescued promptly. Dr. Albert Craig of the University of Rochester in New York interviewed many revived drowning victims and concluded that blackouts occurring in shallow water come on suddenly, without warning, and often without any memory of what happened. The perils of excessive hyperventilation should be emphasized in all swimming and diving programs.

CAUSE AND PREVENTION OF DROWNING

It is not the intent of this paper to list all possible causes of drowning; however, the major causes are an overestimation of one's swimming ability, muscle cramps, and shallow water blackout. Panic and aimless struggling elevate the body's demand for oxygen and reduce the swimmer's probability of survival. Other potential causes not covered here include hypothermia, bodily injuries, biological hazards, severe water conditions, existing medical conditions, and failure of breathing equipment.

Important factors in the prevention of drowning include knowing one's own limitations, swimming in areas with lifeguards, swimming with a partner, and a familiarity with local shore, surf, and bottom conditions. Particular attention should be paid to water current, tides, unusual shoreline and underwater structures, biological hazards (microbes, sharks, venomous sea snakes, man-of-war, tangling seaweeds, etc.), and chemical contaminants.

Although it is possible to suppress the urge to breathe by a variety of methods, it is not possible to escape from the eventual hypoxia. Knowing that hypoxia offers no stimulus for breathing until very low oxygen partial pressure is reached, it is important to heed the first warning signs. Alcohol and other drugs are incompatible with water-related activities; both accelerate heat loss, retard coordination and judgment, and give a false sense of invincibility. Exercising in water also accelerates heat loss. One should not remain in the water for prolonged periods. Even in Hawaii's relatively warm waters, critically low body temperatures (35°C or 95°F) can be reached in one hour of continuous immersion. Below this temperature, coordination and judgment may be impaired.

RESUSCITATION AND MANAGEMENT

ABC and CPR

Handling a struggling and panic-stricken swimmer requires special skills. Therefore, it is of paramount importance to start basic first aid as soon as the victim has been retrieved from the water. Begin by clearing the victim's airway and following with artificial respiration to restore breathing. Chest compressions, at about one per second, should be administered immediately, and once CPR is initiated, someone should call for an ambulance.

The speed with which the victim receives professional medical treatment determines whether they will completely recover or suffer permanent irreparable physical and neurological damage. When the victim reaches the hospital, the partial pressure of oxygen of the patient's blood requires immediate medical attention. Additional treatments include: managing plasma electrolytes, maintaining acid-base balance and fluid volume, preventing infection from inhaled water, slowly rewarming hypothermic patients, and minimizing brain activity for comatose patients.

COLD WATER DROWNINGS SURVIVAL

Under some circumstances, humans can survive submersion in cold water for long periods of time. In 1987, an 11-year-old North Dakota boy survived submersion for 45 minutes under icy water. On arrival at the hospital, his body temperature was 80°F (26.7°C). The accident occurred in early December and he was discharged from the hospital in time for Christmas. Even more remarkable, his physical and mental performance were normal for his age group one year after the incident. Before the North Dakota boy's experience, the most celebrated case involved a five-year-old Norwegian boy who, in 1974, plunged through a partially frozen river and was plucked out of the water 40 minutes later. There have been many instances where people have arrived at the hospital clinically dead, with no vital signs, low body temperature, and dilated and inactive pupils, and have survived. These cases demonstrate the high probability of surviving long submersion in cold water. Survival after long submersion is possible because of **diving reflexes** and the lowered body temperature (**hypothermia**), which reduces the body's demand for oxygen.

Exhaustive and aggressive revival procedures should be tried in cases of cold water drowning before giving up. In cold water drowning, the golden rule for treating victims is "nobody's dead until they are warm and dead." On the contrary, surviving long submergence in warm water is limited, except for the lucky few receiving prompt and timely interventions. Invariably, neurological **sequelae** occurs after six minutes of submergence. In recent years, revival cases of prolonged submersion as long as 45 minutes underwater have appeared in the literature. Some survivors recover completely with no residual signs of nerve damage. Invariably, what saved these lucky few involved cold water and "diving reflexes."

Diving Reflexes

Involuntary apnea occurs when the face comes into contact with cold water. This is part of the mammalian "diving reflexes," which play an important role in the daily life of diving mammals, such as whales, dolphins, and seals. The other component of the diving reflexes causes slowing of the heart (**diving bradycardia**) and redistribution of blood flow in favor of the brain and the heart by shutting blood to practically all other tissues (**selective vasoconstrictions**), thus conserving oxygen for these two vital organs. Obviously, the functioning of the brain and the heart also fails if this condition persists, but diving reflexes buy time for humans. Apneic response is most important for surviving an accidental fall in water, because apnea prevents inhalation of water, thereby allowing the blood redistribution reflex to take effect. Investigators agree that diving reflexes are weak in humans, but under some circumstances, the reflexes are sufficient for surviving an incredibly long submersion.

For the past 20 years, under the auspices of the University of Hawaii Sea Grant College Program, researchers at the Department of Physiology, John A. Burns School of Medicine have been studying the physiology of breath-hold diving. Dr. Suk Ki Hong (with the University of Hawaii until 1975), has published extensively on Korean and Japanese women divers, both in the field and in the laboratory. In the laboratory, Dr. Hong and Dr. Lin studied changes in blood chemistry, lung volume, gas exchanges, factors shortening or extending breath-hold time, and cardiovascular function during the course of voluntary apnea. In the laboratory, diving reflexes can be induced by voluntary face immersion in water. Two startling revelations came from these studies.

Cold water enhances both the bradycardia and vasoconstrictive responses. Reports abound on strong diving bradycardia in humans, ranging from 5.6 to 25 beats per minute. These frighteningly low heart rates may persist for 20 seconds or more with no noticeable ill effects. Slow heartbeat reduces the heart's demand for oxygen and is valuable during times of limited oxygen supply.

A second discovery from the studies is that voluntary breath-hold time can be astonishingly long. An example is the case of Robert Foster, who in 1959 stayed underwater for 13 minutes and 42.5 seconds in a motel pool, after extensive deep and fast breathing (**hyperventilating**) with oxygen. However, this was not the longest underwater duration on record (see suggested reading for more facts). It must be stressed, however, that hyperventilation before submersion (**diving**) is extremely dangerous (see **shallow water blackout**). These extremely long breath-hold times aside, the authors have observed many subjects breath holding for four minutes or longer on a single breath of air, even without prior hyperventilation. Besides the will to continue breath-holding and tolerance of discomfort, the supply-demand relation of oxygen holds the decisive role in how long a breath can be held. Therefore, increasing the oxygen supply is one way to extend breath-holding time; the other is by reducing the demand for oxygen, thereby making the available oxygen last longer.

CONCLUSION

Serious submersion incidence occurs accidentally or by willful submersion exceeding physiological limits. Insufficient oxygen supply to the brain causes loss of consciousness and death unless the victim is rescued and revived promptly; however, evidence shows that victims of drowning may survive long submersion. Therefore, revival efforts should be aggressive and exhaustive in cases of cold water drowning. Near-drowning victims may recover completely following treatments or may suffer permanent disability. Educational programs are the most cost effective means of preventing drowning and surviving with minimum sequelae. While submerged at depth, the diver's urge to resume breathing is masked by the elevated partial pressure of oxygen, which falls drastically during ascent, and blackout may occur before reaching the surface. Shallow water blackout is a major cause of drowning with swimmers; ironically, especially with good swimmers. Learning to sense and heed the urge to resume breathing can prevent shallow water blackout in the water and, thus, drowning.

What to Do

- Learn basic swimming skills.
- Learn rescue and CPR techniques.
- Know your own limitations.
- Swim with a partner or in areas with lifeguards.
- Be aware of shore and water conditions.
- Heed the sensation of the urge to breathe.
- Be comfortable with diving equipment

What Not to Do

- Hyperventilate before submersion.
- Participate in underwater swimming competitions without supervision.
- Remain in water for prolonged period (hypothermia and fatigue may result)
- Continue in-water activity when tired.
- Overestimate one's own swimming ability.
- Drink alcoholic beverages or use other drugs before swimming.

SUGGESTED READING

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GLOSSARY

ABC: Clear the *airway*, restore *breathing*, and reinstate *circulation*

Apnea: The absence of breathing

Breath-hold Diving: Free diving, skin diving without respiration equipment

CPR (Cardiopulmonary Resuscitation): Mouth-to-mouth resuscitation and chest compressions to aid restoration of breathing and blood circulation

Diving Reflexes: Cardiovascular and pulmonary responses to submersion, which consists of apnea, slowing of heartbeats, and selective vasoconstriction to favor the heart and the brain

Drowning: Death in water or death after rescue because of the direct effects of cerebral anoxia

Hyperventilation: Overbreathing in relation to the body's metabolic need, so that carbon dioxide in the lungs tend to fall below normal; a dangerous way to prolong diving time

Hypothermia: Body temperature significantly below 37°C (98.6°F)

Hypoxia: Subnormal level of oxygen in air, blood, or tissues

Near Drowning: Survival from a serious submersion accident

Sequelae: Afteraffects of an injury

Serious Submersion Accident: Accidents related to inability to keep the head above water

Shallow Water Blackout: Blackout in water caused by hypoxia, often occurring during the ascent phase of a breath-hold diving