DIVER EDUCATION SERIES

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THERMAL STRESS AND THE DIVER

Lee H. Somers, PhD

The human body is homeothermic, or warmblooded, and must constantly interact with its external environment in an effort to maintain thermal equilibrium. It basically operates in a very narrow temperature range. Slight cooling of the body can produce discomfort, and continued cooling can cause serious, if not life-threatening, physiological changes. The same is true if the body is heated. Cold induced deterioration in both motor and mental processes is considered to be the major limiting factor relative to diver performance, comfort, and safety. All divers have experienced hypothermia, or a subnormal body temperature, in varying degrees at one time or another. Most divers associate cold stress and hypothermia with polar or temperate region waters and fail to recognize the "thermal drain" that can be associated with diving in the tropics. On the other hand, hyperthermia, or abnormally high body temperature, may unknowningly place some divers at high risk.

HEAT LOSS

Thermal balance and immersion heat loss are affected by a number of variables. The first of these is obviously water temperature and the effectiveness of the diver's thermal protection garments. The length of exposure becomes a critical factor, as does the magnitude of metabolic heat generation. The individual's body fat composition; body mass and surface area; and physiological/psychological acclimatization must also be considered. In generalized terms, an individual of large body mass produces more heat and can tolerate longer exposures to cold water than a small, thin individual.

As the body begins to cool there is a mobilization of its heat generation and insulation resources to resist the cold. This response is characterized by peripheral vasoconstriction (constriction of circulating blood near the body surface) and increased metabolic activity in an effort to prevent a drop in the body's core temperature. Active movement of body tissues generate heat, carbon dioxide and water. As the body continues to cool the most obvious metabolic activity will take the form of shivering thermogenesis. Thermogenesis is simply the generation of heat.

The first diver evidence of heat loss, just below the comfort level, is **cold sensations.** This is followed by cutaneous vasoconstriction and, then, increased muscle tension which are not obvious to the diver. Even before a person begins to shiver visibly, muscle tension is measurable on an electromyogram. Normal core temperature is 37°C. At 36°C sporadic shivering begins. This initial shivering can be suppressed if the diver makes a conscious effort and, in fact, a working diver may not exhibit shivering at this point because of muscular activity. As the diver continues to cool, shivering increases and causes a further rise in oxygen consumption. As the diver reaches the stage of uncontrollable shivering, the oxygen consumption is two to five times the normal [1]. By this time the dive should have been terminated and rewarming procedures initiated.

When the core temperature drops to 35°C, the diver will experience mental confusion and impairment of rational thought. Death by drowning is a real possibility. A diver should never "push" or "be pushed" to this point. Continued exposure to cold and decreasing the core temperature below 35°C causes loss of memory, poor articulation, sensory and motor degradation, and amnesia [1]. Many investigators believe that cold creates a distraction in the diver that interfers with his or her work, and indeed, safety [2]. Childs observes, "distraction due to discomfort may cause the diver to ignore threats to his safety underwater and finally, realizing he is in danger, he may be in further difficulty because of loss of power and dexterity in his hands" [3].

In order to better understand "heat loss" and the use of diver thermal protection systems, it is necessary to consider the areas of the body where metabolic heat is produced. About 16 percent of the metabolic heat is produced in the brain, about 56 percent in the core of the trunk, and about 18 percent comes from total skin and muscle. The remaining 10 percent comes from the total skeleton, connective tissue, and other structures [4].

Divers tend to concentrate their thermal protection around the trunk and often compromise protection to the head. It is interesting to note that the head, a relatively small portion of the body, produces a great deal of heat. Furthermore, the peripheral vasoconstriction effectiveness varies considerably from one part of the body to another. The hands and feet experience considerably high vasoconstriction and cool very quickly [4]. This results in reduced finger dexterity, tactile (touch) sensitivity, and kinesthetic (musculoskeletal) sensation. However, total heat loss in these areas is low. On the other hand, scalp circulation in the head does not experience this vasoconstriction or "shut down" [1]. The amount of continual heat loss can be quite substantial if the head is not properly protected.

SILENT HYPOTHERMIA

Divers have only recently developed an awareness of "silent" or "undetected" hypothermia resulting from long, slow body cooling. Field experience showed that after several days of work in 27°C water temperature scientific divers were reluctant to continue to dive. Divers working in the temperate waters of southern California sometimes "forgot what they were doing." Polar divers often neglected to complete their research task.

In most cases the divers generally would not indicate that they were cold, just fatigued or unwilling to dive again [5].

What was the problem? The participants at the "Prevention of Cold Injury" workshop sponsored by the Undersea Medical Society and National Oceanic and Atmospheric Administration reached the following conclusion, "The fatigue and impaired cognition [was] due in large part to the slow body cooling of divers even in tropical waters" [5].

For years scientists failed to make the connection between cold and diver fatigue for three reasons: (1) "thermal macho"; (2) lack of appreciation of the importance of thermal protection equipment; and (3) the insidious nature of "undetected hypothermia" in long, slow body cooling. "Thermal macho" is perhaps best described by Diver/Engineer Robert Stinton of Diving Unlimited International. To quote, "Divers will rarely admit that they are cold. So they become fatigued and are reluctant to dive again. But they will never admit it's because they are cold except in the most extreme situations. Even if they say they're not cold, they pay the price in reduced performance, fatigue, and loss of motivation" [5].

Several authorities on cold water immersion suggest that long, slow cooling of the body does not stimulate the shivering response and thermogenesis. When cooling is encountered by a swimsuit-clad diver immersed in 28 to 33°C water or diving in wet or dry suits in 15°C or colder water, the mean skin temperature can remain close to the usual comfort zone (33° C). Consequently, the thermal drain from the body to the water is insidious and hardly noticed by the diver until the core temperature drops 1 to 2°C and shivering supervenes [5].

Bachrach considers "silent" or "progressive" hypothermia as "perhaps the major hazard to the diver in cold water" [2]. In commercial diving, investigators have implicated cold as a major cause of diving casualties, particularly the silent, progressive, insidious onset of hypothermia of which the diver is unaware [3, 6].

Divers often disregard the possible cumulative thermal effects of repetitive diving. Following the initial dive the diver returns to the surface where he/she may experience superficial skin rewarming, but, little or no recovery of depressed core temperature. Each successive dive creates additional and cumulative thermal drain. This is why many divers are often too fatigued to care for their equipment following a day's diving activities and may sleep on the way back from the dive site [7]. This "thermal debt" may continue to accumulate over successive diving days. Sport diver complaints of "getting colder" toward the end of a week of tropical diving are not uncommon, especially if the diver is not using some form of thermal protection. One such female diver described her tropical experience, "After a few days of diving I would return to my room and huddle on the floor under a hot shower for an hour after a dive." It takes time, rest, food, and, sometimes, aggressive rewarming procedures to replace lost heat energy.

REWARMING THE DIVER

The preferred method of rewarming a chilled diver is to allow the diver's own biological processes to rewarm his/her body over time with plenty of rest. Remove the diver from the water to a warm, protective shelter where the suit can be removed without added thermal degradation. The diver should dry as soon as possible and dress in adequate warm, dry clothing.

If aggressive rewarming is required in order that the diver may return to diving immediately or conventional rewarming appears to be inadequate, the diver may be immersed in a tub of comfortably hot **circulating** water [8]. Neither showers nor still baths appear to be as satisfactory as a circulating tub immersion. The water must circulate around the body to maximize heat transfer. **Do not** remove the diver until sweat appears on his/her forehead.

DETERMINING PERFORMANCE DEGRADATION AND DIVE STATUS

One simple method of determining performance degradation is by monitoring the diver's hand writing [8]. Have the diver sign his/her name prior to entering the water. When the diver surfaces, have him/her sign under the first signature again. Repeat this procedure for each successive dive. If the signature shows a continual degradation, this indicates a lack of blood flow to the muscles of the lower arm area and, therefore, the accumulation of a thermal debt. In male divers the testicles will rise to maintain thermal balance as the body cools. One authority suggests that an indication that the diver is completely rewarmed is when the testicles descend to normal position again [8]. This may or may not be a reliable indicator of thermal recovery.

HYPERTHERMIA IN DIVING

If the body is exposed to high ambient temperatures, it can gain heat. Consequently, the body must increase the amount of heat that it loses in order to prevent a rise in core temperature. Through vasodilation, or increasing the size of the peripheral blood vessels, more blood is carried to the periphery where it can be cooled.

Under certain conditions this process can be somewhat limited. If the diver is encased in a hot, humid environment such as a hyperbaric chamber or a **diving suit** with direct exposure to the sun, the heat loss process may be insufficient. Normally, the evaporation of perspiration will promote significant cooling of the body's surface and, thus, loss of heat from peripheral circulation. What happens if the ambient environment will not facilitate evaporation? Apparently, little heat loss occurs and the increasing peripheral temperature is transmitted to the core [4].

Overheating can lead to heat aesthemia when a person just doesn't feel well; heat cramps; heat exhaustion; and heat stroke [4]. The onset of problems can be alleviated only if the danger signs are recognized. In the case of heat cramps, for example, the painful muscle spasms develop with increasing regularity as the concentrations of sodium and chloride ion in the blood and tissues decrease. Heat exhaustion occurs next. In heat exhaustion the diver will start sweating profusely, experience a lowering of blood pressure, and feel weakness and vertigo. The end result is a heat stroke in which the diver develops an extremely high fever and lapses into coma. Sweat glands stop functioning, and the body temperature rises at an alarming rate. This condition can be terminal.

The adversities of hyperthermia are rare in most scuba diving situations. However, some divers dressed in thermal protection suits and exposed to hot sun and high ambient temperatures for significant periods of time on boat decks or beaches have complained of "not feeling well" and have exhibited symptoms that suggest the early stages of heat exhaustion. One diving suit manufacturer acknowledges "heat stress" as a potential problem and recommends specific precautions for divers exposed to high temperature surface conditions [8]. Pouring cool water down the neck and sleeves of the wet suit diver can be very effective. Divers who must remain dressed in dry suits may be cooled by placing their hands and wrists in ice water, blowing air into the suit, and placing cool, wet towels or running water over the head. Divers and dive teams using dry suits for warm weather diving operations should anticipate such problems in divers experiencing long surface exposures while suited and take specific precautions.

SUMMARY

Both cold stress and heat stress problems should be anticipated by divers. Silent or progressive hypothermia associated with long, slow cooling of the body appears to not produce shivering and thermogenesis until significant core temperature drop has occurred. Cumulative effects of hypothermia are evident in tropical as well as temperate and polar area diving. The increased use of dry suits provide improved thermal protection against cold; however, hyperthermia is potentially of greater concern during warm weather surface exposure.

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