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HYPERTHERMIA IN DIVERS AND DIVER SUPPORT PERSONNEL

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Hyperthermia in divers and diver support personnel

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diving equipment
heat stress
heat stroke

The encapsulation required to protect divers and surface personnel from harmful pathogenic microorganisms in tropical, temperate, and artificially heated contaminated environments can result in hyperthermia. To compound the problem, decontamination procedures often extend the length of time divers remain suited, often while they stand in the hot sun, and may limit the aid that can be given to them if they are hyperthermic. Tenders equipped with protective suits and breathing apparatus are also prime targets for hyperthermia.

The NOAA Diving Program conducted a series of experiments which showed that certain types of equipment may significantly extend a diver's safe exposure time in a high-temperature environment. Divers' subjective reports regarding the degree of hyperthermia they experience are very unreliable; we found that divers can easily extend their stays in a high-temperature environment to the point of heat stroke. A positive-pressure, water-filled suit was developed, which was capable of maintaining a sufficient positive pressure within the suit to prevent leaks in case of puncture and to maintain appropriate body temperature.

PROCEDURE

During the early phases of testing of polluted water diving apparatus by the NOAA Diving Program (NDP), hyperthermia became an obvious limiting factor to workload and dive duration at moderate temperatures (28°C). Diving suits normally limit or eliminate evaporative cooling of the skin. Breathing gas temperatures are approximately equal to water temperatures when using either scuba or surface-supplied diving equipment. Decontamination procedures following dives in contaminated water may require the diver to remain suited for up to 20 min; often in the hot sun.

As part of a series of diving apparatus (USN MK 12 Helmet) integrity tests involving a 20-min period of light exercise, which stressed the potential failure points of the apparatus, NOAA divers began to experience problems of overheating. Further tests were conducted to determine the upper temperature limits of the standard air-filled suits, and the more recently developed positive pressure water "suit under suit" (SUS).

Helmet, skin, and rectal temperatures of the divers were monitored continuously. Electrocardiographic (ECG) tracings were obtained during brief rest periods. Signals from the sensors were sent to the surface monitoring equipment via a shielded cable exiting through the diver's helmet. Initial tests were conducted in conjunction with integrity/decontamination studies at the NOAA Experimental Diving Unit. These tests involved diving in heated ammonia/fluorescent dye solutions in a 12-ft deep tank. The temperatures were increased on a daily basis until upper thermal limits were achieved.

Diver discomfort in air-filled suits became significant at temperatures in excess of 38°C. Tests were terminated after 20 min in 42°C water due to rapidly rising rectal temperatures and high heart rates. Rectal temperatures continued to rise after the removal of the diver from the water and during decontamination and undressing, suggesting an "afterise phenomenon."

During the same series, divers were able to complete three consecutive exercise periods in 44°C water using the SUS apparatus perfused with 22°C water. Hyperthermia was not limiting in these tests and higher temperatures could not be obtained due to system heating limitations.

During the next series of tests, skin temperatures were measured on the chest, back, and crotch, as well as helmet and rectal temperatures and periodic ECG tracings. A heat exchanger was installed to provide temperature control of the cooling water.

In-line flow meters were used to determine water and air flow to the diver. A standard air flow rate of 6 ACFM was used throughout the test. Water flow was set at 7.5 LPM of 22°C water. The same 20-min light exercise series used in earlier tests were used in this new test series.

Initial tests in the 46°C range were uneventful. At 49°C, an unanticipated incident resulted in a significant overheating of one of the divers. The cornstarch used on the outside of the inner suit to allow easy entry into the outer suit became "cooked" by contact with the hot outer suit and turned to "gravy." The "gravy" plugged the screens on the ankle exhaust valves and prevented adequate perfusion of the lower portion of the suit, causing a rapid heating of the diver. Although he was uncomfortable, the diver was unaware of the extent of hyperthermia that he was experiencing. The diver was removed from the water and cooled with cold water towels around the head, chest, and shoulders. The following day the same diver successfully completed a 1.5 h dive in the 50.5°C water with a stable rectal temperature and elevated heart rate. On a subsequent dive an older diver (44 yr) exhibited a progressive increase in premature ventricular contractions (PVCs) as the dive progressed. The dive was terminated after 20 min.

Breathing a hot gas and having the head exposed to hot air while the body surface is maintained cool is an unusual situation for humans. The PVCs experienced by 1 diver and tachycardia by another caused sufficient concern to terminate the test series and to consider 50°C the maximum acceptable temperature for divers breathing ambient temperature gas with body cooling. Cooling of helmet gas may allow a significant increase in the maximum operational temperatures of diving.

We also noticed an increase in body temperature of surface tenders as they suited up in protective suits, breathing apparatus, and cooling vests. The increase in body temperature of surface personnel was relatively slow, up to a certain point, after which it would start to rise rapidly. This phenomenon was occurring among both the surface personnel and the divers. We identified this as the critical point, because once the individual's temperature started to rise rapidly, it took a significant time to cool him or to get him out of the adverse environment.

At least when working under the hot August sun, we could not maintain a stable temperature in the actively cooled tenders unless they stopped working and sat in the shade. We also observed that after they had unsuited and sat in the shade, where they obviously underwent a net body cooling, they still registered an increasing rectal temperature.

CONCLUSIONS AND RECOMMENDATIONS

1. The highest recommended temperature for diving operations using helmets and air-filled suits is 40°C.
2. The highest recommended temperature for diving operations using helmets with ambient temperatures breathing gases and body cooling is 50°C.
3. Divers subjective feelings regarding their degree of hyperthermia are very unreliable and a diver can easily extend his stay in hot water to the point of heat stroke. Reliable diver monitoring, to determine the degree of hyperthermia, is a recommended safety consideration when diving in heated water.

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