CONTINUOUS CORE TEMPERATURE MONITORING OF SEARCH AND RESCUE DIVERS DURING EXTREME CONDITIONS

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ABSTRACT

Objectives. To study the feasibility of continuously monitoring core temperatures of search and rescue divers, to compare core temperature gradients occurring during warm and cold diving events, and to identify conditions under which divers are subjected to extreme temperatures. Methods. Between June 1994 and March 1995, emergency medical technicians (EMTs) from two midwestern dive teams volunteered to ingest an encapsulated temperature sensor developed for the National Aeronautics and Space Administration. The capsule monitored continuous core temperatures and transmitted the data to a recorder worn under the divers’ dry suits. Results. Twenty male EMTs, mean age 34 years and mean body weight 184 pounds, were monitored during training. Nine dives were ice dives, with ice thickness averaging 9 inches, and mean ambient temperatures of 33°F. Eleven dives were warm-water dives; average water temperature was 70°F and mean ambient temperature was 74°F. The average time spent in the dry suit was 95 minutes, and in the role of safety diver, regardless of the season. Divers showed a mean increase in core temperature of 1.0°C, while the warm-water divers showed a mean increase of 1.2°C. Divers experiencing the most extreme fluctuations were those in the role of safety diver, regardless of the season. Divers reported more subjective discomfort during ice dives than during warm-water dives. Conclusions. Continuous monitoring of body temperature during the duration of dive operations is possible, but labor-intensive. Safety measures to protect divers from extreme core temperature fluctuations should focus on the safety diver as well as the active diver. Key words: continuous monitoring; core temperature monitoring; search and rescue divers.

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Over the last decade emergency responders—police, firefighters, and emergency medical technicians (EMTs)—have acquired the tools and expertise to carry out sophisticated technical rescue operations. Technical rescue can include response to hazardous materials incidents, high-angle rescue, or deployment of search and rescue dive teams. The highest priority is assigned to ensuring the safety of these professionals.

Search and rescue divers require regular training sessions to maintain their skills with scuba and rescue equipment and to practice emergency rescue protocols. Rescue operations often take place in environments that may contain hazards to the diver.

The diving equipment used is intended to protect the diver while providing maximal maneuverability. Variable-volume dry suits made of vulcanized rubber are used during all seasons to provide protection from the elements and objects in the water. The total weight of the dive gear, including scuba, communication system, and dry suit, is approximately 100 pounds. Although the same equipment is used during all seasons and weather conditions, divers may vary the level of insulation worn beneath the dry suit according to the water temperature.

One of the many potential hazards rescue divers experience is an abrupt change in body temperature. Rescue operations are typically carried out with paired dive teams. One diver remains above the surface, fully outfitted as the "safety diver" ready to assist the active diver if necessary. In warm weather there is the potential for hyperthermia, particularly for the safety diver who is often stationed in direct sunlight for long periods of time, during which heat can accumulate rapidly within the dry suit. Conversely, diving during frigid weather puts both divers at risk for rapid thermal loss and the development of hypothermia.1,2

Accurate determination of body heat storage or heat debt in individuals exposed to the artificial environment of a dry suit is difficult. Until recently, core temperature monitoring of divers was accomplished using rectal probes and measurement was possible only before and after the dive. Using the CoreTemp System, the possibility of monitoring core temperatures continuously during the diving was studied to describe the extent of body temperature fluctuations experienced by these rescuers.
MATERIALS AND METHODS

This was a prospective, observational study designed to analyze continuous core temperatures in search and rescue divers. Thermal gradients were compared during warm and cold diving events, and conditions under which divers may be subjected to extremes of temperature were identified.

The study took place between June 1994 and March 1995, at three search and rescue dive training sites. The participants included 20 EMTs employed by established fire department dive teams in Cuyahoga Falls, Ohio, and the Ottawa County Sheriff's Department in Holland, Michigan. Eleven of the divers were in warm water and nine were in cold water.

The subjects in this study were required to be at least 18 years of age and currently engaged in fire department search and rescue dive activities. They must have successfully completed the fire department's annual physical examination, have undergone the presuit field physical, and be otherwise qualified to dive. The study was approved by the institutional review board, and each subject gave written consent to participate in the study. Volunteers were excluded if they had a history of gastrointestinal (GI) disorder or GI surgery or were intending to undergo magnetic resonance imaging within the next seven days.

The encapsulated temperature sensor used to monitor core temperatures was developed by the Johns Hopkins University Applied Physics Laboratory in conjunction with the National Aeronautics and Space Administration. The device is contained in a 0.6 by 0.4-inch silicone capsule. This ingestible capsule contains a telemetry system, microbattery (nickel-cadmium), and quartz crystal temperature sensor. It is marketed as the CoreTemp System (Human Technologies, St. Petersburg, FL), and has been approved by the Federal Drug Administration for one-time use in human beings.

Once the capsule is ingested, data are continuously transmitted to an ambulatory recorder worn under the dry suit. The temperature readings were transferred to computer for analysis and graphic representation.

The divers underwent a presuit physical examination administered by either the medical advisor of the dive team or a physician researcher. The examination includes a medical history, measurement of vital signs, and the Rapid Field Neuro Exam. This short neurologic examination includes items designed to rapidly evaluate cranial nerves, equal sensation to touch, muscle tone, balance, coordination, and baseline vital signs.

All the subjects were volunteers who offered to participate in the study by ingesting the capsule and wearing the monitoring device during their regular dive training exercises. We monitored one diver at a time.

| TABLE 1. Anthropometric and Temperature Data for All Subjects |
|------------------|------------------|---------|------------------|------------------|------------------|
|                  | Age (Years)      | Weight (Kg) | Ambient Temperature (°C) | Time in Suit (Minutes) | Baseline Core Temperature (°C) | Highest Core Temperature (°C) | Change in Core Temperature (°C) |
| Ice dives        |                  |            |                      |                    |                           |                             |                                |
| Subject 1        | 38               | 773        | 34.0                | 95                 | 37.4                       | 38.4                       | 1.0                            |
| Subject 2        | 34               | 85.0       | 34.0                | 145                | 37.4                       | 37.8                       | 0.4                            |
| Subject 3        | 35               | 72.7       | 35.0                | 172                | 36.1                       | 38.0                       | 1.9                            |
| Subject 4        | 29               | 94.5       | 35.0                | 100                | 37.6                       | 37.9                       | 0.3                            |
| Subject 5        | 43               | 78.6       | 35.0                | 189                | 37.5                       | 38.5                       | 1.0                            |
| Subject 6        | 34               | 93.6       | 37.0                | 73                 | 37.3                       | 38.6                       | 1.3                            |
| Subject 7        | 25               | 85.0       | 37.0                | 131                | 37.4                       | 38.9                       | 1.1                            |
| Subject 8        | 38               | 77.3       | 29.0                | 120                | 37.1                       | 38.2                       | 1.1                            |
| Subject 9        | 28               | 88.6       | 29.0                | 50                 | 36.8                       | 37.7                       | 0.9                            |
| Mean: subjects 1-9 | 34            | 83.6      | 33.9                | 119                | 37.2                       | 38.3                       | 1.0                            |
| Warm-water dives |                  |            |                      |                    |                           |                             |                                |
| Subject 10       | 39               | 86.4       | 72.3                | 66                 | 36.2                       | 39.2                       | 3.0                            |
| Subject 11       | 35               | 72.7       | 70.2                | 90                 | 36.2                       | 37.6                       | 1.4                            |
| Subject 12       | 35               | 109.0      | 81.9                | 90                 | 37.2                       | 38.8                       | 1.6                            |
| Subject 13       | 34               | 80.0       | 76.3                | 104                | 38.6                       | 38.9                       | 0.3                            |
| Subject 14       | 35               | 81.8       | 67.5                | 41                 | 36.8                       | 37.8                       | 1.0                            |
| Subject 15       | 34               | 80.0       | 69.0                | 61                 | 36.5                       | 37.5                       | 2.0                            |
| Subject 16       | 40               | 88.6       | 74.5                | 107                | 37.0                       | 38.1                       | 1.9                            |
| Subject 17       | 38               | 77.3       | 83.1                | 70                 | 37.6                       | 38.2                       | 0.6                            |
| Subject 18       | 33               | 86.4       | 84.9                | 90                 | 38.0                       | 38.9                       | 0.9                            |
| Subject 19       | 35               | 72.7       | 67.0                | 126                | 36.7                       | 37.1                       | 0.4                            |
| Subject 20       | 32               | 86.4       | 62.0                | 34                 | 37.5                       | 37.8                       | 0.3                            |
| Mean: subjects 10-20 | 35           | 83.8      | 73.5                | 80                 | 37.1                       | 38.2                       | 1.2                            |
and in an effort not to interfere with the training exercises, we made no attempt to control the type or duration of underwater activities of the subjects. However, all the divers practiced sweep patterns using surface-supplied air.

The core temperature sensor was ingested at least 20 minutes prior to suiting up to allow time for equilibration within the GI tract. No fluid or other oral intake was permitted during the monitoring phase. Temperature was continuously monitored until after the diver had completed the training scenario and removed the dry suit. A postsuit physical examination was conducted as soon as the diver removed the dry suit.

In addition to continuous monitoring of the diver's core temperature, information about the diver's activity and subjective temperature assessment during training was recorded. Total bottom rime, time in the dry suit, ambient temperature, and water temperature were documented.

**RESULTS**

Twenty male EMTs, mean age 34 years (range 25-38) and mean body weight 184 pounds (range 160-208), were monitored during training with dry suits. Nine dives were ice dives, with an average water temperature of 37°F above the thermocline and ice thickness averaging 9 inches. The mean ambient temperature was 33°F. Eleven dives were warm-water dives; the average water temperature was 70°F and the mean ambient temperature was 74°F. Anthropometric data and information about the dives are shown in Table 1.

The average time spent in the dry suit by all divers was 95 minutes, and the mean total bottom time was 15 minutes. The ice divers showed a mean increase in core temperature of 1.0°C, while the warm-water divers showed a mean increase of 1.2°C. Divers experienced the most extreme fluctuations while in the role of safety diver, regardless of the season. The safety diver is fully equipped and ready to dive at a moment's notice, positioned on the surface near the active diver. In our ice dives, the safety diver was waiting on the ice near the entry hole. During the warm-water dives, the safety diver was waiting either on the dock or in a boat. During these training sessions, all monitored divers acted both as the safety diver and subsequently as the active diver. The divers reported more subjective discomfort during ice dives, most of which were complaints of cold extremities, particularly the hands.

Figure 1 is a graph of core temperatures recorded during one of the ice dives, and Figure 2 is a graph of core temperatures recorded during a warm-water dive.

**DISCUSSION**

We found that it was feasible to obtain continuous recordings of core body temperature throughout search and rescue training dives when the divers were wearing dry suits. None of the subjects reported any difficulty in swallowing the capsule, most stated that the silicone coating made the capsule fairly "slippery," and it was easily swallowed with a little water. We successfully monitored 20 divers during the training session. However, seven additional attempts were unsuccessful. Three ice dives resulted in no data recorded, one due to a malfunctioning temperature capsule, and two from unknown causes. Four warm-water attempts were also unsuccessful. These resulted in incomplete and inaccurate data, most likely due to difficulties encountered as a result of the tight fit of the bulky recording device under the dry suit and the activities of the divers during their training exercises.
Two warm-water divers experienced a change in mean body temperature greater than 2° C. This is beyond the maximal heat tolerance limit recommended by physiologists and represents a potential for the development of heat-related illness and the accompanying danger to the diver and those dependent on his or her assistance.\(^5,6\) The two individuals who experienced this extreme increase in temperature did so while in the role of safety diver, 30-50 minutes prior to active diving. These increases in core temperature experienced by these two divers continued until at least 10 minutes after the completion of the dive.

Core temperature readings among ice divers were variable, with most of the divers experiencing slightly elevated temperatures while diving. Overall, ice divers experienced a mean increase in core temperature of 1.0°C. Once again, the most extreme temperature fluctuations were experienced during the time the diver was in the role of safety diver. Divers reported more subjective discomfort during ice dives than they did during warm-water dives, with most complaints directed toward the discomfort caused by cold extremities.

LIMITATIONS AND FUTURE STUDIES

As might be expected when collecting physiologic data in the field as opposed to the controlled conditions of the exercise physiology laboratory, our data were influenced greatly by the varying environmental conditions. As this was strictly an observational study with the intent of testing the feasibility of using this equipment, no attempt was made to control the environmental conditions under which each diver participated. In addition, it appears that there is a tremendous variability in the manner with which these individuals responded to exposure.

This method of measuring core temperature was more convenient for the divers than the standard method involving the use of a rectal probe, and also enabled assimilation of a complete picture of thermoregulatory changes during the dive. In this study, the data were not available in a real-time manner, because we were required to wait for the diver to divest himself of the recorder so that the information could be downloaded. However, technology is currently available to allow telemetry of real-time data to a command post; our budget did not allow us this luxury.

Core temperature measurements from the GI tract are relatively similar to rectal temperatures, although there may be slight variations along the tract due to the location of the probe at the time of measurement.\(^7\)

CONCLUSIONS

This is the first report to describe continuous core temperature monitoring in search and rescue divers during extremes of weather conditions. Safety measures to protect divers from extreme core temperature fluctuations should focus on the safety diver as well as the partner performing the rescue, because safety divers are more likely to experience extremes in core temperature. To protect physical functioning, the most technologically advanced equipment should be utilized, and safety divers should limit their exposure time according to the climate.

References


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