BRIEF REPORT

Use of Handheld Sonar to Locate a Missing Diver

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Objective.—The purpose of this study was to investigate whether a handheld sonar device significantly reduces the mean time needed to locate a missing diver.

Methods.—This institutional review board approved, prospective, crossover study used a voluntary convenience sample of 10 scuba divers. Participants conducted both a standard and modified search to locate a simulated missing diver. The standard search utilized a conventional search pattern starting at the point where the missing diver (simulated) was last seen. The modified search used a sonar beacon to augment the search. For each search method, successful completion of the search was defined as locating the missing diver within 40 minutes.

Results.—Twenty total dives were completed. Using a standard search pattern, the missing diver was found by only 1 diver (10%), taking 18 minutes and 45 seconds. In the sonar-assisted search group, the missing diver was found by all 10 participants (100%), taking an average of 2 minutes and 47 seconds (SD 1 minute, 20 seconds). Using the nonparametric related samples Wilcoxon signed rank test, actual times between the sonar group and the standard group were significant ($P < .01$). Using paired samples t tests, the sonar group's self-assessed confidence increased significantly after using the sonar ($P < .001$), whereas the standard group decreased in confidence (not statistically significant, $P = .111$).

Conclusions.—Handheld sonar significantly reduces the mean duration to locate a missing diver as well as increasing users' confidence in their ability to find a missing diver when compared with standard search techniques.

Key words: injury prevention, handheld sonar, missing scuba diver

Introduction

Although the incidence of reported diver related fatalities has remained reasonably stable at 3 to 6 per 100,000 since the 1970s, the popularization of self-contained underwater breathing apparatus (scuba) diving continues to attract more participants who have significant medical comorbidities, are poorly conditioned, and are of advancing age.¹ Such persons are at increased risk for dive-related injuries. The most common disabling injuries leading to death are asphyxia, arterial gas embolism, and acute cardiac conditions. The most commonly identified triggers are air supply problems, emergency ascent, entrapment/entanglement, and buoyancy trouble.² Considering that only 6 of the 73 fatalities recorded in 2008 by the Divers Alert Network were solo dives,³ one may infer that if a diver can break the chain of events leading to either his or her own or a dive-buddy's disabling

injury, some deaths may be preventable. An unplanned separation alone can lead to anxiety, possibly resulting in poor decision-making, or increased physical exertion leading to exhaustion. The use of handheld sonar to quickly find a buddy may have the potential to break this chain of events leading to a distressed diver.

When a dive team becomes separated, a common practice is to perform a 1-minute underwater search and then surface. Few devices exist for divers to find each other underwater; divers are usually limited to their senses of sight and sound (eg, percussion devices such as clickers or striking a dive cylinder with a metal bar and lights). If the dive-buddy is still missing upon surfacing, a more formal search may take place. Owing to the urgency of the rescue and the typical remoteness of the dive site, professional rescuers will rarely take part in dive rescues. The immediate rescuer is often the missing diver's own buddy or other divers at the scene. Several diver-training agencies teach rescue techniques in intermediate-level diver training courses. These courses teach several search patterns, depending on water conditions, begin-

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ning at the site where the missing diver is last seen. It was the authors' intent to investigate whether a handheld sound navigation and ranging (sonar) system would affect the time required to find a missing diver.

Methods

STUDY DESIGN

This prospective, crossover study was approved by the Madigan Army Medical Center Internal Review Board, Tacoma, Washington. A voluntary sample of scuba divers who met the study's inclusion criteria (current dive certification, no deficiencies on standard dive medical screening, and between 18 and 50 years of age) were recruited from a military hospital located at Fort Lewis, Washington, and a military-based scuba club to serve as both participants and supervising divers. scuba divers were required to be basic or advanced open-water certified scuba divers. A power analysis determined that a minimum of 10 dives per group was required.

A dive schedule was created based on the availability of participants. Participants were assigned to 1 of 2 dive groups. Each diver in the first group started with the sonar search, while each in the second group started with the standard search. An information brief was given by the study staff to include voluntary enrollment, safety, and diving instructions. All participants were provided with standard scuba reference material describing the dictated nationally recognized search methods for a lost diver. This information also includes a description and basic operating instructions of the Mark Track sonar dive equipment (RJE International, Irvine, CA). The Mark Track sonar navigation system was chosen for use owing to commercial availability and suitability to test our objective. The system has the ability to transmit 0 to 15 4-ms pulses per second; switch selectable, at a frequency of 72.5 kHz. These pulses are detectable from as far as 4000 feet away. Participants also completed a questionnaire before and after conducting the search dives to measure the degree of procedural confidence.

Participants conducted both a standard and modified (equipped with a commercial, transmitting sonar beacon) search to locate a submerged, clothed dummy. In contrast to the standard search, the missing diver in the modified search was equipped with a commercial, transmitting sonar beacon. Both searches utilized a standard scuba expanding square search pattern that started at the point at which the missing diver was last seen. For each of the search methods, successful completion of the search was defined as locating the missing diver within 40 minutes. Success rate, start time, and time to successful identification of the missing diver for each method

was recorded. Time started upon descending from the surface buoy and stopped when the missing diver was located.

SETTING

The dives took place at a public access beach in Puget Sound, with an average water temperature of 55°F and visibility of 15 to 20 feet. Two dive sites were set up in advance with safety equipment, dive buoy indicating the last known location, and a simulated missing diver (with or without the sonar dive transmitter) placed 100 feet from the dive buoy submerged to a depth of 30 feet. The dive buoy was placed in the center of the search area and was approximately 200 feet from shore. Participants strictly followed the dive schedule, ensuring that dive site was not seen before the dive, to eliminate learned bias. All participants started searching for the missing diver by the dictated search method. However, divers in the sonar-assisted search arm were instructed to swim directly toward the transmitter signal once it was detected. After the missing diver was located, the supervising diver led the participant to shore and surfaced. At all times, the dive supervisor swam directly above the participant and monitored time, location, and safety. If 40 minutes elapsed or a safety issue occurred, the dive was safely terminated by the supervising diver. The participant spent at least 90 minutes of recovery time before the subsequent dive. The surface interval was determined by using standard dive tables with a maximum depth of 50 feet and absolute bottom time of 45 minutes. After all divers completed their initial dive and recovery time, they performed their second dive.

STATISTICS

The Wilcoxon signed rank test to compare nonparametric related samples was utilized as the populations among the sonar-assisted and standard search group differed (only 1 missing diver was found in the standard search group). Pre-dive and post-dive procedural confidence was measured through a survey using a 9-point Likert visual analogue scale for both the standard and sonar-assisted search. Values were compared using paired samples *t* tests. A value of $P < .05$ was taken to be statistically significant. Results are presented as mean $\pm$ SD.

Results

Twelve participants were initially enrolled into the study. Two dropped out because they were not able to complete both dives, owing to either time constraints or equipment failure. The average age of completing participants was

34 $\pm$ 6.8 years. Participants consisted of 3 open-water divers, 3 advanced open-water divers, and 4 rescue divers. Participants had previously completed anywhere from 7 to 100 previous dives, with a median of 20 dives.

A total of 20 dives was completed: 10 using a standard search pattern, and 10 sonar-assisted searches. Using the standard search pattern, the missing diver was found by only 1 participant, with a search time of 18 minutes and 45 seconds. With the sonar-assisted search, the missing diver was found by all 10 participants with an average search time of 167 $\pm$ 47 seconds. The difference in times between the sonar group and the standard group was significant.

The standard search group participants self-scored an average of 4 $\pm$ 1.4 regarding their ability to find the missing diver on the pre-dive questionnaire. The post-dive average was 2.8 $\pm$ 1.7; the average decrease in confidence was 1.6 $\pm$ 1.8. The sonar-assisted participants scored an average of 5.3 $\pm$ 1.5 for their ability to find the missing diver on the pre-dive questionnaire. The post-dive average was 8.9 $\pm$ 0.3, with an average increase in confidence of 3.6 $\pm$ 1.6. Using paired samples *t* tests, the sonar group significantly increased in confidence after using the sonar.

Discussion

Our study reveals that a searching diver equipped with sonar and minimal prior training can easily and quickly locate a missing diver in less than 3 minutes, on average. The missing diver was found 100% of the time with sonar. Furthermore, all the participants reported an increasing confidence in their search skills with the sonar-assisted search pattern as compared with searching without sonar. By means of comparison, without sonar, the missing diver was found in only 1 instance, with a time of 18 minutes, 45 seconds.

Previous articles and smaller scale studies discuss the difficulty in finding a missing diver and potential benefit of an emergency position indicator rescue beacon in open-water missing diver scenarios.⁴ We believe this study is an initial step toward testing handheld sonar's applicability in finding separated/missing divers. Although this study cannot be used to draw any definitive conclusions about the use of sonar as an adjunct to diver rescue and survival benefit, it appears to prove that the concept and application are feasible, perhaps serving as the basis for larger, more formal studies.

STUDY LIMITATIONS

Some considerations in study design limitations should be acknowledged. Participants were not randomly as-

signed (owing to time constraints). Given the crossover design and small sample size, it is possible that the order in which search patterns were performed may have affected the outcome. The crossover design may have led to learning effect, as participants were not naïve to the second search pattern. That was mitigated by altering the search patterns enough to minimize the learning effect. Also, our study focused on reducing mean duration to locate a missing diver, and did not look at the times associated with the initial recognition of the missing diver, or the time required for successful extraction, which, if prolonged, may have a negative impact on the final outcome.

Equipment failure and the inherent limitations of sonar should additionally be acknowledged. Equipment failure due to sustained water damage to the receiving sonar beacon was an issue on the initial attempt to perform the sonar-assisted search pattern. The device was unusable until it was dried. The water damage was likely due to the age of the equipment initially used, as well as to errors in properly assuring it was watertight before use. That reflects a design flaw that would limit the equipment's use, as it must be meticulously inspected before use to insure that all seals are seated properly. The transmitting beacon has the ability to transmit at different pulse rates, hypothetically allowing it to detect and differentiate among as many as 15 different divers. However, the use of more than 1 transmitting beacon at the same time was not tested. This feature would need to be effective for widespread use as there would be the potential for more than 1 dive group to be within 4000 feet of each other at the same time. Furthermore, sonar has known inherent limitations of echo effects and line of sight. The more significant is line of sight, which could entirely block the sonar signal if the missing diver is inside a boat or cave, behind a rock, or inside a depression. Echo effects occur when the sonar signal is reflected or refracted, and will give the illusion that the signal is coming from a different place. That can usually be mitigated, as the true signal will be the strongest. Our study utilized flat ocean floor topography, and thus did not account for these limitations.

Conclusions

Sonar used as an adjunct to dive search patterns reduces the mean duration to locate a missing diver when compared with standard search techniques. The data suggest that the application of sonar as an adjunct is feasible and promising. The concept and application has the potential

to serve as the basis for larger studies and to facilitate development of a future devices and protocols.

Acknowledgments

We would like to thank Brian Klokeid, MD, JD, an emergency physician and master scuba diver for his invaluable on-scene medical support, as well as David Brand, PA-C, for on-scene administrative support. The views expressed are those of the authors and do not reflect the official policy of the Department of the Army, the Department of Defense, or the US Government. The investigators have adhered to the policies for protection of human subjects as prescribed in 45 CFR 46.

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