Dive Computer Program Management in Scientific Diving

Michael A. Lang
Smithsonian Institution
Office of the Under Secretary for Science
PO Box 37012
Washington, DISTRICT OF COLUMBIA 20013-7012 U.S.A.

The Smithsonian Institution Scientific Diving Program is a large civilian scientific diving program in the United States through which, since 1990, approximately 140 active scientists have logged over 3,400 dives annually in a multitude of locations around the world. In 2005, the decision was made to develop a management tool to assist in streamlining and monitoring Smithsonian diving activities: a web-based virtual dive office. Launched in 2007, DECOSTOP has provided an efficient mechanism to submit diver applications and dive plans, maintain diver medical, equipment, training and certification records, enter dive log information and review and authorize diving projects. Besides providing the benefit of paperless-database functionality, since 2010, all Smithsonian-authorized diving requires the use of a Smithsonian-issued dive computer from which all dive profiles are now directly uploaded to a database in DECOSTOP for review and collation. This web-based virtual office has dramatically improved the efficiency of the management of the Smithsonian Scientific Diving Program and monitoring of occupational dive profile exposures.

INTRODUCTION

Dive computer (DC) evolution has taken place at a rapid rate since the first modern-day, diver-carried electronic dive computer (the ORCA Industries' EDGE) became commercially available in 1983 housing a 12-compartment model based on Spencer et al.'s Doppler studies and reduced no-decompression limits (Huggins, 1989) through to the 2011 VR3 dive computer that is programmable for air, enriched air nitrox, mixed gas, and rebreather use that comes with a web site proclamation stating "…we have all the answers…" Looking forward, Lang and Angelini (2009) presented the future of dive computer development with benefits from advances in consumer electronics technology (high resolution color display, rechargeable battery, GPS receiver, underwater communication and navigation and EPIRB-Emergency Position Indicating Radio Beacon), monitoring technology integrated into the algorithm (heart rate monitoring, skin temperature measurements, oxygen saturation measurements, and inert gas bubble detection) and advances in decompression physiology research.

The emergence of dive computers has raised a number of questions regarding their safety, evaluation procedures and guidelines for use in the scientific and recreational diving communities (Lang and Hamilton, 1989; Wendling and Schmutz, 1995), and for this particular project, the Norwegian commercial diving community. Uncertainty was indicated regarding the dive computer's ability to manage multiple deep repetitive dives, which was reconfirmed when it was noted that little data existed on repetitive diving in general (Lang and Vann, 1992). However, dive computer effectiveness in providing real-time guidance on decompression status and ascent rate monitoring has been established since 1983. Guidelines for dive computers have provided a framework for their operational use but the issue of how to validate a dive computer remains unresolved, other than with reference to the analogous validation of decompression tables (Schreiner and Hamilton, 1989).

A significant problem of testing the efficiency of dive computers is the disagreement over, or poor definition of, a valid end point to measure. Clinical symptoms of decompression sickness (DCS) may be totally inadequate in this regard, but recording the amount of gas produced by a profile also has its drawbacks with respect to timing and exact location of measurements. Accepting this argument, for this particular discussion it appears reasonable to assume that once a diver reports a problem, the diving emergency system is activated and the emergency oxygen kit is deployed, then that dive profile on that particular day for that individual diver perhaps cannot be recorded as "safe." Follow-up neurological examination and chamber treatment would be the determinant of whether DCS was appropriately diagnosed as the symptom.

DIVE COMPUTER EVALUATION CRITERIA

The process of determining which dive computer to approve should include knowledge of the effectiveness of the decompression model being used, i.e., 'what's in the box' and is it an acceptable model? An algorithm is simply a means by which one can extrapolate limited experience to new circumstances and is only as reliable as the database upon which it was tested. Determination of an acceptable independent validation process of dive computers would appear to include knowing what type of test profiles were performed. Some would argue that human subjects testing with Doppler monitoring should be part of this consideration. An acceptable level of DCS risk should also be prescribed and operational reliability data examined. A final consideration would be to determine how applicable to a specific diving community's mission a dive computer is in addressing, for example, long shallow and short deep dives, staged decompression dives, multi-level dives, repetitive multi-day dives, reverse dive profiles, ascent rates, altitude diving, and parameters for flying after diving.

There are four ways, in ascending order of practical value, to decide if a computer is physiologically acceptable (Edmonds, 1989):

- Testimonials and personal experiences by using satisfied customers as spokespersons, but the repeated diving of the computer to the limit is often lacking;
- Compliance with decompression theories if there were unanimity of opinion on a single theory of decompression and no empirical modifications to tables;
- Compliance with established diving tables, although progressive table modification has deleted unsafe profiles, and if decompression for same single and repetitive fixed-level profiles were comparable; and,
- Comparison with hazardous diving profiles recognizing that there exists minimal information on safety limits of multi-level diving and even less information on decompression and repetitive deep dives.

The safety of divers could be enhanced by ensuring that: DCs are tested to confirm a reliability at least equal to the US Navy tables and specifically towards the extremes of recommended depths, dive durations and surface intervals; DCs are sequentially demonstrated to be relatively safe for square-wave and repetitive dives before extrapolating to multi-level dives; written recommendations be incorporated into the DC function identifying their safe use; and, the DC be demonstrated to be valid physiologically, mechanically and electronically reliable through the same validation procedures as a new diving table would need to be (Edmonds, 1995).

A relatively new mechanism to ethically meet some testing requirements with a minimal need to actually expose subjects in a pressure chamber was described by Peterson (1995). Guidelines to use past experience and field exposures as part of the validation process were provided by Schreiner and Hamilton (1989) and may be applicable in this consideration of which dive computers might be best suited to meet the needs of Norwegian commercial divers.

Validation protocol suggestions have been difficult to make with the vast number of past and current commercially available dive computers being used. Further, many dive computers are really multiple computers (10) in one with a number of user-selectable settings, as for example the SUUNTO Vytec set with RGBM 100% (P0/A0, P0/A1 or P1/A0, P0/A2, P1/A1 or P2/A0, P1/A2 or P2/A1, P2/A2) or RGBM 50% (P0/A0, P0/A1 or P1/A0, P0/A2, P1/A1 or P2/A0, P1/A2 or P2/A1, P2/A2). A comparison of 30 msw no-stop limits among different dive computers reveals a range of 19 to 7 minutes depending on the aforementioned DC settings. Further, if the factors influencing DCS susceptibility (e.g., depth, time, ascent rate, temperature, profile sequence, breathing mixture, exertion level, physical condition, limb positioning, hydration level, age, body composition) are programmed into the DC, it becomes infinitely variable and forms an impossible task to test all combinations and validate their efficiency. Therefore, the Smithsonian Scientific Diving Program decided to select a common dive computer through its Standardized Equipment Program for training, operational and safety purposes.

SMITHSONIAN SCIENTIFIC DIVING PROGRAM

The Smithsonian Scientific Diving Program (SDP) is a large U.S. civilian scientific diving program. Since 1990, approximately 140 active scientists log over 3,400 dives annually in a multitude of locations around the world. SDP Unit Diving Officers (DOs) are stationed at laboratories across the latitudinal gradient of the western Atlantic (Maryland, Florida, Belize and Panama) and in the Washington DC area. In 2005, the need was identified to develop a management tool to assist in streamlining and monitoring tasks among scientific divers, DOs and the Scientific Diving Officer (SDO): A proprietary web-based virtual dive office. Launched in 2007, DECOSTOP has provided an efficient mechanism to submit diver applications and dive plans, maintain diver medical, equipment, training and certification records, enter dive log information, and review and authorize diving projects under Smithsonian auspices. Earlier attempts at modifying existing more complex programs to meet our specific needs were abandoned and DECOSTOP was structured using some elements from a dive log program provided by the National Oceanic and Atmospheric Administration. Besides the benefit of paperless-database functionality, dive profile information collected through the dive log upload function has proven superior to previously collected data. Since 2010, all Smithsonian-authorized diving requires the use of a Smithsonian-issued dive computer from which all dive profiles are now directly uploaded to a database in DECOSTOP for review and collation. Former dive log information submitted as “shells” (i.e., maximum depth and time) provided no measure of the physiological stress level of a particular dive nor any abnormalities considered to be triggers for DCS such as rapid or multiple ascents, violation of ceilings, or inadequate decompression.

1. Diving safety regulations

The SDP diving safety regulations pertaining to dive computers have been continuously updated since 1990 and were derived primarily from the output of diving safety research projects conducted specifically for the scientific diving community by the SDP (Lang and Hamilton, 1989; Lang and Egstrom, 1990; Lang and Vann, 1992; Lang and Lehner, 2000; Lang, 2001). The SDP has long maintained that the ultimate responsibility for safety rests with the individual scientific diver, with buoyancy control being a critical skill in slowing ascent rates and fundamental to safe diving practices. Only those makes and models of dive computers specifically approved by the program's Scientific Diving Control Board (SDCB) may be used. Since 1990, the program has approved SUUNTO, UWATEC, and Orca Industries models and since 2010 has implemented the SUUNTO ZOOP as the standard required dive computer to be worn on all Smithsonian scientific dives. Each diver relying on a dive computer to plan dives and indicate or determine decompression status must wear his/her own unit and be proficient in its use and it is strongly recommended that each diver also dive with a back-up dive computer. A diver should not dive for 18 hours before activating a dive computer to use it to control his/her diving. Once the dive computer is in use, it must not be switched off until it indicates complete offgasing has occurred or 18 hours have elapsed, whichever comes first. Only one dive in which the no-decompression limit of the dive computer has been exceeded may be made in any 18-hour period. On any given dive, both divers in the buddy pair must follow the most conservative dive computer. If the dive computer fails at any time during the dive, the dive must be terminated and appropriate surfacing procedures initiated immediately. In an emergency situation breathing 100% oxygen above water is preferred to in-water air procedures for omitted decompression.

Ascent rates are controlled at 10 m/min from 20 m and do not exceed 20 m/min from depth. A stop in the 3-10 msw zone for 3 to 5 minutes is required on every dive and multi-day repetitive diving requires that a non-diving day be scheduled after multiple consecutive diving days. Reverse dive profiles for no-decompression dives less than 40 msw with depth differentials less than 12 msw do not lead to a measurable increase in DCS risk. A PO_2 of 1.6 atm is the maximum limit for enriched air nitrox for which standard scuba equipment is approved for up to 40% oxygen content.

Scientific divers are further cautioned about exceeding model and/or tested DC limits, blindly trusting the dive computer (i.e., the brain still needs to be turned on to make decisions from the DC numbers being displayed), ignoring decompression requirements, continuing to dive with a DC that malfunctioned on a previous dive or switching dive computers during a day of diving, and that repetitive multi-level, multi-day diving needs allowances to adequately offgas slow tissue half-times.

2. Dive computer selection criteria

Much consideration was given to the selection criteria of a dive computer that would meet our needs. REEF NET SENSUS PRO dive recorders were ruled out in favor of the provision of real-time dive information from a similarly priced dive computer. Both puck-type and air integrated computers were considered from SUUNTO and UWATEC. Dive computer operation should be effortless through easy-to-use push buttons, wet switch activation and a straightforward menu-based user interface. A DC with metric/imperial unit option, date and watch function of 12/24 hours, water resistance to 100 m and light weight were prioritized features. A bright phosphorescent LCD display and an option of wrist unit or console-mounted dive computer assist in ease of reading displayed data. Multi-mode versatility should include a programmable function for enriched air nitrox (EANx) mixtures of 21% to

50% O_2 and adjustability for partial pressures of oxygen (pp O_2) between 1.2 - 1.6 bar, CNS% and OTUs (oxygen toxicity units).

Further considerations included the type of algorithm and documented experience with it (the SUUNTO RGBM algorithm in SDP's case). Ascent rate and available no-deco time need to be displayed graphically with clear color-coded indicators and the availability of visual and audible alarms when necessary was also a desirable feature. The DC had to be powered by a user-replaceable 3V lithium battery, and have a power indicator and low battery warning. Because of the SDP's polar and tropical diving work, DC operating temperatures should range between $0^{o}C$ – $40^{o}C$, and have a storage temperature between $-20^{o}C$ - $50^{o}C$. Other functions had to include altitude adjustability, ascent rate monitor, dive planner, decompression data, log book memory, maximum depth of 100 meters, 3-30 sec sampling rate option, safety stop countdown, and temperature recording.

The implementation logistics started with the establishment of policy that required use of SDP-issued ZOOP dive computers. A dive computer training module was developed and the SUUNTO ZOOP user guide was made available on the SDP web site. An online dive computer exam tests the theoretical knowledge of the diver on dive computer function and use. The SDP Unit Diving Officers download dive profiles into the database by a cross-referenced entry by dive plan authorization number.

The resources required to implement this program include sufficient dive computer acquisition, management, shipping, and tracking of the dive computers, dive computer batteries and supplies, PC-interface cables and downloading, and a diver training program for dive computer use.

3. Database integration of dive profiles

Scientific divers are required to log all dives via DC download on DECOSTOP, using web browser interfaces to interact with an SQL database through a relational database management system provided by the Smithsonian Office of Information Technology. The major goals of implementing a dive computer monitoring program are to streamline the dive logging process for increased accuracy in data collection and providing enhanced dive log information. Dive log data is retrieved directly from the dive computer that each individual diver wears by uploading log files into DECOSTOP. The final step automatically extracts dive log files from the dive computer .SDE file (Steganos Disk Encryption), populates the dive log table with dive log data, and creates a graph from the data per dive.

To enhance the 'Upload Dive Profile' function all .XML files (Extensible Markup Language) are extracted from the .SDE files. Each .XML file, along with data entered within the upload form, is inserted into the database as a separate dive log record. To create a graph from the uploaded .XML files, the function of the icon on the dive log list was changed to a graphical representation of the data contained in a dive .XML file similar to graphs currently displayed in the SUUNTO Dive Manager 2 (DMS2). The diver is able to see dive depths and times at points within the graphical display.

The development strategy for this program included scripting an add-on ColdFusion program function to automatically extract .XML files from the .SDE file as it is uploaded into the DMS2 database. This function then automatically inserts the .XML files into the database as BLOB (Binary Language Object) fields. Finally, using an .XSL (XML Style Sheet) transform, a web-based graphing system was built using .HTML (Hypertext Markup

Language) and .CSS (Cascading Style Sheets). The DECOSTOP virtual office is accessed through https://www.si.edu/dive.

CONCLUSIONS

The overall issue with dive computers remains the mechanism of repetitive dive control. On balance, the 28-year operational experience with dive computers has demonstrated that their advantages over table use outweigh the disadvantages. The large range of dive computer variability demands that the establishment of their selection criteria meets a particular diving community's specific needs. An important element of this approach is the characterization of a community-specific universe of 'safe' dive profiles for which the computer is effective through use of a dive computer monitoring program. Dive computer validation to the specific model's limits, as has been traditionally tested with dive tables via human subjects testing, is not likely to occur because of the time and expense involved and the infinite combination of dive computers and settings.

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