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REVERSE DIVE PROFILES WORKSHOP
Washington DC. October 29-30, 1999

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Key Words

Decompression illness, diving theory, physiology, tables.

For many years recreational scuba divers and their instructors have embraced a maxim that it is unacceptable to perform a repetitive dive to a deeper depth than a previous dive, or to perform the deeper part of a single multilevel dive after a shallower part. These two manifestations of the same dive pattern are known (by some) as "reverse dive profiles." While there is widespread recognition among recreational divers that reverse dive profiles are forbidden, such profiles are apparently being performed anyway. It is not so clear where the rule against reverse dive profiles came from or how significant it really is.

In recent years the recreational diver has seen the development and refinement of dive computers and "do-it-yourself" decompression computational programs for personal computers. Most of these do not specifically prohibit the pattern of reverse dive profiles and will allow the calculation of such profiles without apology. The primary consequence is that there may be less no-stop bottom time available on a repetitive dive. In professional practice, neither the military nor commercial diving communities prohibit or even recognise reverse dive profiles as unique, except in rare instances. These facts have recently called into question the long-standing prohibition against reverse dive profiles in the recreational diving community.

Since there are incentives of greater allowable bottom time for the recreational diver to observe the prohibition of reverse order and perform dives only in "forward" order, the rule has not been subject to serious questioning in the past. However, for scientific divers who mainly use the same techniques as recreational divers but who may have more demanding mission objectives for their dives, to follow the rule can impose a significant operational limitation. It seemed worthwhile to re-examine the rationale for this rule. This was recently done in a high-level international Workshop sponsored by the Smithsonian Institution and some other interested organisations and held 1999 October 29 and 30 at Smithsonian facilities in and near Washington DC.

The Workshop was organised by Michael Lang, Diving Officer and head of the Smithsonian Institution's Scientific Diving Program, and by Charles Lehner, Diving Physiology Laboratory, University of Wisconsin, Madison. Michael is not new to workshops on challenging subjects, having organised earlier workshops on dive computers, biomechanics of ascent rates, polar diving, and repetitive diving, all under the auspices of the American Academy of Underwater Sciences. In addition to the Smithsonian and AAUS, other sponsors of this Workshop include DAN, DEMA, and Dive Training Magazine.

Before even touching on the technical aspects of the Workshop, one truly unique aspect of it should be mentioned, the high level of talent that was assembled to tackle the issue of reverse dive profiles. The participants included most of the decompression modellers and theorists in current practice, and many practical developers of decompression tables, hardware, and software, military and commercial diving operational managers, diving training people and organisations, media representatives, manufacturers, and an impressive array of medical experts who see the results of decompression practices when they do not work quite right.

Participants making formal presentations (with co-authors who were not there in parentheses) in order of their appearance included: Michael Lang, John Lewis, Glen Egstrom, David Yount, (Eric Maiken), Erik Baker, Bruce Wienke, (Tim O'Leary), Hugh Van Liew, Peter Tikuisis, Ron Nishi, Charles Lehner, Valerie Flook, Alf Brubakk, (Olav Eftedal), Paul Weathersby, Wayne Gerth, Michael Gernhardt, (Ed Thalmann), Dick Vann, Petar Denoble, Karl Huggins, Till Mutzbauer, Bill Hamilton, Jon Hardy, Peter Mueller, Terry Overland, Drew Richardson, Karl Shreeves, (Jed Livingstone), Duke Scott, Ted Maney, Steve Sellers, Walter Jaap, Richard Moon and Tom Neuman. Those attending the Workshop and taking part in the discussions, but without formal presentations, represented an equally impressive array of expertise.

The Workshop's objective was to examine whether reverse dive profiles are cause for increased risk. To see if there was a real reason to prohibit such profiles, the issue was addressed along two lines—analysis of existing diving data and evaluation by decompression modelling.

The first session defined the issue of reverse dive profiles and included speculation on just where the "prohibition" against them originated. Prior to the Workshop some of the participants were not familiar with the term "reverse dive profile." Review of the literature in search of the origin of the prohibition suggests that the rule probably had less to do with safety issues and more to do with "optimising" bottom time over a series of dives. This comes from gas loading considerations that allow more useable bottom time by doing the deep dive first.

The Workshop accepted the definition of a reverse dive profile, but one definition that was not quite agreed upon was that of a "bounce dive." To recreationally oriented divers this usually means going straight down and coming straight back up, without decompression stops, a pattern resembling a "spike." In commercial and military diving, any dive not involving decompression from saturation would usually be regarded as a bounce dive, even if it involved a long decompression. Thus, the term "bounce dive" should be interpreted in context.

The next two sessions concentrated on physics, physiology, and modelling. Several of the latest decompression models were employed to analyse selected series of reverse dive profiles. Among the modelling approaches, bubble formation and/or growth models were prevalent. Although there was diversity between the bubble models, they tended to arrive at some similar conclusions. For example, most call for lower allowable supersaturation gradients on the initial stops ("deep stops") and shorter no-decompression limits than conventional dissolved gas models. The bubble models included David Yount's varying permeability model (VPM) also known as the "tiny bubble" model, Bruce Wienke's reduced gradient bubble model (RGBM), the Duke University bubble volume model, the DCIEM bubble evolution model based on Doppler scores, a gas dynamics model by Valerie Flook based on Van Liew's concepts, and Michael Gernhardt's tissue bubble dynamics model.

In his presentation, Hugh Van Liew made the argument that direct experimental validation is needed about the existence and role of micronuclei for bubble formation in mammalian tissues. This includes whether or not such gas nuclei can be "crushed" to the point of elimination or inactivation. In another presentation it was shown that the reverse dive profile may have a higher predicted incidence of DCS, but for pairs of no-stop dives the differences were trivial and a decompression using the US Navy tables would be adequate. However, for dives involving decompression stops or for more than two dives in a row, it looked like these tables might not provide a reliable decompression. All of this pointed toward an urgent requirement for more information, and to this end Alf Brubakk suggested an animal model that might at least show which profiles result in the most bubbles.

Another session included a panel discussion by several dive computer manufacturers. Many of the older computers on the market use conventional dissolved gas (Haldanian) algorithms that take into account only gas loading and supersaturation limits (M-values), and do not specifically consider the order in which dives are conducted. In these cases, the user manuals accompanying the computers may recommend against reverse dive profiles. Some of the latest dive computers incorporate algorithms that are based to varying degrees on bubble models; these computers have specific warning features or penalties for dive patterns associated with increased risk (spike, yo-yo, repetitive dives with excessive pressure differentials, etc.).

Regarding data, many horror stories have been associated with reverse profiles, the classical one being the instructor making a short, deep dive to release the anchor chain after a day of diving and getting severe DCS. This is hard to interpret because it is a very small "n", there is usually no denominator, and buddy divers doing the same profile may be unaffected. Other data showing say 100 dives may be insufficient for statistical analysis, but one comment put this into perspective: "We are a better off having that 100 dives than no observations at all." A number of participants reviewed some substantial data collections, including the US Navy, commercial diving, chamber data, DAN records, various sets of recreational dive data, and some significant contributions from field experience.

An argument can be made that the present lack of data that says reverse profiles are dangerous could be, in part, due to the arbitrary prohibition against them that has been in place for many years, so not so many of these dives have been done.

Although there were some problems with reverse dive profiles in isolated examples, the conclusion drawn from overall analysis of the actual diving data was that reverse profiles *per se* have not shown a higher risk for DCS than forward profiles. However, this holds most confidently when the differential pressure for the reverse profile is not too great, but this also means that depth is a factor, since you cannot get big differentials without having significant depth. It appears that decompression tables, algorithms and dive computers are adequately handling the issue of reverse dive profiles in the field.

Another observation is that this subject seems to be very much a matter of repetitive diving, and in general, this is handled quite differently across the many decompression algorithms.

After all the presentations were complete, Richard Moon and Tom Neuman provided "individual perspective" summaries of the information that had been presented at this Workshop. The discussion was then turned to the floor for purposes of arriving at a list of Findings and a Conclusion for the Workshop.

The discussion got a little heated when it came time to come up with a Conclusion or Recommendations. Several of the folks who work with bubble models had serious reservations about a "complete retraction" of warnings against doing reverse dive profiles.

In other words, the bubble models suggest that you might really get into trouble on an improperly planned or executed reverse dive profile. Many were concerned that divers, especially inexperienced sport divers, would get the wrong message about reverse profiles and think that it was okay to do them without any special consideration.

A couple of key concessions were obtained by the bubble modellers. It was pointed out that practical diving experience showed that there had not been many problems with reverse profiles, but bubble models showed that there could be. So, some wording was adjusted to make it clear that it was only in the diving experience that there were few problems, not that there is a lack of evidence of any kind that reverse profiles are or could have a higher DCS risk. The sentiment prevailed also that there should be a pressure differential limit, or "delta-P," noting that most of the safely executed reverse profiles were 12 msw (40 fsw) or less between the repetitive dives. Another point of agreement was that the sport diving limit of 40 msw or 130 fsw should apply to any relaxation of current prohibitions on reverse profile diving.

The Workshop Findings

* Historically neither the US Navy nor the commercial sector have prohibited reverse dive profiles.
* Reverse dive profiles are being performed in recreational, scientific, commercial, and military diving.
* The prohibition of reverse dive profiles by recreational training organisations cannot be traced to any definite diving experience that indicates an increased risk of DCS.
* No convincing evidence was presented that reverse dive profiles within the no-decompression limits lead to a measurable increase in the risk of DCS.

Conclusion

The Workshop found no reason for the diving communities to prohibit reverse dive profiles for no-decompression dives less than 40 msw (130 fsw) and depth differentials less than 12 msw (40 fsw).

The proceedings have been published (295 pages in soft cover).

Lang MA and Lehner CE. Eds. Proceedings of the Reverse Dive Profiles Workshop. Washington DC: Smithsonian Institution, 2000

The proceedings are available from AAUS, 430 Nahant Road, Nahant, MA 01908. (781) 581-7370 x334. aaus@neu.edu. The retail price is $25.00. They are also available from Best Publishing Co., DAN and UHMS.

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RISKS REPORT SHEDS NEW LIGHT ON DEATHS

Anon

Key words

Accidents, deaths, incidents, risk.

The biggest causes of death among sport divers are entrapment and entanglement, air embolisms and reckless deep dives. And, directly related to embolisms, rapid ascents are the single most common type of diving incident.

These and other fascinating incident patterns have emerged with the publication of an in-depth study by the Health & Safety Executive (HSE).

The report *Scuba Diving: A Quantitative Risk Assessment* has been prepared by the Paras research group to quantify risks to diving scientists.

However, as few statistics exist for scientific diving, the report is actually based on sport diving information provided by the British Sub-Aqua Club (BSAC) and by the Divers Alert Network (DAN).

The BSAC provided information on 849 incidents from 1990 to 1994, of which 57 were fatalities; and DAN provided data on 277 fatalities to US citizens from 1992 to 1994.

A number of cases were excluded for various reasons including 48 fatalities of a cardiovascular nature, because the study was required to assess divers who would almost certainly have passed a diving medical.

Total analyses therefore covered about 1,000 incidents, of which 286 were fatalities.

The researchers broke cases down into types, including entrapment in closed environments, entanglement, rapid ascents and air embolisms, reckless diving, solo diving, states of health and loss of consciousness for unknown reasons.

They then broke these areas down further to establish causal patterns, which make for illuminating reading.

The most frequent principal causes of fatalities were entanglement and entrapment, air embolism and reckless deep dives.

Curiously, loss of consciousness was the next most frequent principal cause of death, research indicating that many divers who could have saved themselves following a serious incident failed to do so and drowned.

The report suggested that there may be a link between extreme fright and loss of consciousness. Key among contributory causes to fatalities was buddy separation. Failure to monitor air supply and inadequate dive briefings came next.

Health factors as possible contributory causes accounted for 2% of BSAC fatalities and 5.1% of DAN fatalities. Conditions encountered included obesity, diabetes, alcoholic effects, meditations, previous surgery, recreational drugs, asthma, AIDS, migraines and ovarian cysts.

The most frequent contributors to incidents, fatal or not, were rapid ascent; bad interaction between diver and boat; bad monitoring of time, depth and air supply; buddy separation; and inadequate dive briefing.

Rapid ascents, however, accounted for fewer breath-hold embolisms than might be thought. About half of all embolisms occurred during normal ascents, indicating that better diver education is required. It is known, for instance, that divers can underestimate the rapid pressure changes that occur in the last 10 m of an ascent.

A major lesson to emerge from the study was that many cases involve not one but two or more causal effects, which build up in a chain reaction to cause the final incident.

No fewer than 93% of the fatal incidents recorded involved multiple contributory causes.

By inference, divers who can recognise small but potentially dangerous problems and take steps to cover for them are much more likely to avoid harmful incidents under water.

Based on projections of numbers of divers, diving hours completed and fatalities, it was calculated that sport diving suffers roughly one death per 5,000 divers per year typical, stated the report, for adventure sports.

A copy of the report, immensely thorough with some case details, is available at £35 from: HSE Books, PO Box 1999, Sudbury, Suffolk CO10 6FS, United Kingdom (Phone +44-1787-881-165. Fax +44-1787-313-995).

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TOO MANY RAPID ASCENTS GET A GRIP, SAYS BSAC

Key words

Accidents, deaths, decompression illness, incidents.

More divers are suffering from rapid ascents due to poor control over their drysuits and BCs. Yet at the same time, overall numbers of incidents resulting in decompression illness are down. And the 17 UK fatalities listed for 1999 represents a drop on 1998 (at 22, a particularly bad year), close to the average over the past five years (16.8), but a rise on the ten-year average of 14.8.

These and many more statistics, plus the incident stories behind the figures, are published in the annual *Diving Incidents Report* compiled by the National Diving Committee of the British Sub-Aqua Club (NDC).

Listing incidents reported by BSAC members and other divers in the UK, and BSAC members overseas, the report provides pointers on the causes of sport-diving accidents.

Of 382 incidents reported, 86 involved DCI, with 98 casualties, down on the 120 casualties for 1998. But the report states that "it is very likely that there are further cases of DCI". Uncontrolled ascents accounted for a higher proportion of incidents than before, indicating, says the report, a need for better training in the use of modern drysuit and BC systems.

Among problems leading to DCI, 31 per cent involved depths greater than 30 m, 29 per cent rapid ascents. 21 per cent miscalculated repeat diving, and 14 per cent missed decompression stops.

A study of depths at which all the in-water incidents commenced showed that the ratio of fatal incidents was "significantly higher" at depths of more than 50 m indicating that the potential for problems increased markedly with depth and backing the BSAC's own stipulation that its members should not exceed 50 m.

The number of incidents involving diver separation from boats leapt from 34 in 1998 to 51 for 1999.

There were 50 cases of boat engine failure and 13 incidences of other boat problems. This bears out the Coastguard's long-standing message that divers need to improve their boating skills and take better measures to ensure boat-todiver contact. If separation does occur, divers need to have effective location devices.

Reflecting on these other facts in the report, compiler Brian Cumming concluded, that: "Most of the incidents... could have been avoided had those involved followed a few basic principles of safe diving practice."