Reverse dive profiles

Reverse dive profiles: the making of a myth. A response

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Key words
Reverse dive profiles, decompression sickness, evidence

Abstract
(Lang MA, Lehner CE. Reverse dive profiles: the making of a myth. A response. *Diving and Hyperbaric Medicine*. 2006; 36: 51-5.)
The original aims of the Reverse Dive Profile Workshop were to challenge the reasoning behind FDPs and to generate an understanding as to where the historical objection to RDPs originated. While there was a lack of definitive experimental evidence advocating RDPs, it was the lack of evidence prohibiting them that was the issue. In their review article 'Reverse dive profiles: the making of a myth', Edmonds, McInnes, and Bennett fail to impose the desired level of uncertainty on the subject of RDPs, in the context of the Workshop's findings and conclusion, and have added little to the debate that took place at the Workshop. We find no reason for the diving communities to prohibit reverse dive profiles within the no-decompression limits for dives less than 40 msw (130 fsw) and depth differentials less than 12 msw (40 fsw).

In their review article 'Reverse dive profiles: the making of a myth',[1] Edmonds, McInnes, and Bennett conclude that the results of a workshop report[2] revoke established procedures advocating forward dive profiles (FDPs) and promote reverse dive profiles (RDPs) as safe and equivalent alternatives. The authors have added little to the debate that took place at the Workshop. Four pages of criticism of an historical document supplemented by five paragraphs of "new data" fail to impose the desired level of uncertainty on the subject of RDPs, in the context of the Workshop's findings and conclusion.

The original aims of the Reverse Dive Profile Workshop were to challenge the reasoning behind FDPs and to generate an understanding as to where the historical objection to RDPs originated. In the Proceedings of the Workshop, we summarised the evolution of the prohibition of RDPs, defined either as two dives performed within 12 hours in which the second dive is deeper than the first; or, as the performance of a single dive in which the latter portion of the dive is deeper than the earlier portion. The collective knowledge and experience of the highly talented body of workshop participants were not likely to be overcome by a predetermined agenda, as implied by Edmonds et al.[1]

The workshop data

While Edmonds et al point to the lack of definitive experimental evidence advocating RDPs, it is the lack of evidence prohibiting them that is the issue. Although we agree that RDPs have become more prevalent in recent years, the ability of divers to manage an acceptable probability of decompression sickness (pDCS) will clearly depend on the extent to which their profiles approximate the prescribed dive computer algorithms and concomitant decompression obligations. The rationale for the ban against RDPs reviewed at the Workshop indicated that it, also, was based on opinion (and theory) rather than evidence. In the absence of supporting evidence, the necessity of a ban was called into question. Forward profiles are not banned even though we know they have been reported to cause DCS.

Accepting the paucity of experimental data directly addressing the reverse profile issue, the Workshop also succeeded in demonstrating that the traditional recreational diving recommendation (deep then shallow) was similarly lacking in sufficient evidence to justify its abolition. We also showed that RDPs were included in the validation of several tables and dive computer algorithms. Edmonds et al appear to discount these historical data, preferring instead to assume that the safety of FDPs is now being revoked in favour of RDPs.

The scientific, commercial, and military operational diving profiles are well documented and an outcome is ascertained for each profile (DCS/no DCS). In that vein, we argue that these operational exposures in fact constitute data and are not opinion based. The scientific diving community's diving data are scrutinized and recorded for US regulatory purposes by mandate of the Department of Labor.[3] From 2000–2005, we have seen no increase in DCS cases from RDPs. Vann et al reviewed the Project Dive Exploration (PDE) data and found no evidence that RDPs had higher DCS risk than FDPs for diving as conducted by the PDE volunteers.[4] Millions of dives are being done each year around the world and we have no idea what the predominant approach to diving is. FDPs may well be favoured due to the historical ban on RDPs. However, information from chamber operations shows that the predominant profiles of divers presenting are FDPs. The hypothesis that there exist

no physiological data prohibiting reverse profiles within the envelope of the Workshop's conclusion stands. Operational data from the diving communities clearly show that FDPs were preferentially driven by logistical and mechanistic considerations for over a half century. Neither the US Navy nor commercial diving operational procedures specifically prohibit reverse profile diving.

The authors quote the Convenor as stating "*Does it really matter in which order dives are conducted as long as one keeps track of nitrogen loads and performs adequate decompression?*" They continue "*The follow-up question that remained unanswered was: do RDPs and FDPs actually have the same decompression obligations, and can we therefore apply the same decompression requirements to them?*" This is incorrect. They ignore what was stated about keeping track of nitrogen loads. On the contrary, FDPs and RDPs were repeatedly recognised as *not* requiring comparable decompression. Edmonds et al misinterpret our conclusion by testing "mirror" profiles, yet nowhere in the findings and conclusion, or in the body of the Proceedings, did we imply that RDPs that were mirror images of FDPs could be safely undertaken. This appears to be the tangent that the authors embarked on.

Edmonds et al have inserted into their argument observations by Huggins, who hinted at the potential for more severe DCS with RDPs from chamber treatment observations,[5] and St Leger Dowse et al, who analysed UK female divers' log books and indicated that symptom rates were higher in those using RDPs.[6] These observations are valid, but in the context of the authors' argument, they are not evidence. Their text suggests that these data support the notion that DCS severity and symptom rates are greater with RDPs. However, as they point out, neither data set reached statistical significance. The odds ratio for Huggins' data was 1.21 (95% CI 0.68, 2.13), arguably not even close to statistical or clinical significance. Furthermore, there was insufficient detail in the data to control for dive profile, maximum dive depth, or any other risk factor.

Regarding the restrictions agreed upon at the Workshop, these were inserted into the conclusion in order to be conservative, and to obtain consensus (since not all participants opined that the RDP 'ban' should be completely abolished). With the stipulations as stated, there was in fact 100% agreement (of 49 participants).

Indeed, Edmonds et al's assertions represent exactly the kind of conclusion that can arise without historical perspective. Presented with the same literature we searched to examine the gradual evolution of the ban on reverse dive profiles, we are optimistic that the authors would similarly conclude that there exists a lack of definitive experimental evidence supporting this ban. However, diving operational history with RDPs can be neither ignored nor changed.

From the modelling perspective presented at the Workshop we remain convinced that it does not matter what the pattern of profile exposure is provided two things are taken care of: quality decompression according to the last exposure, and not unwittingly creating bubbles at an early stage, which are then ignored.

The animal experiments

Edmonds et al's evidence for the making of a reverse-profile myth resides in a series of animal experiments. However, the myth-debunking extrapolation to humans, or to the Reverse Dive Profiles Workshop findings and conclusion, is inappropriate. As reported, this study's results have no bearing on the real world of diving.

Dive severity can influence the conclusions of a study. The key question is when do the dive profiles become severe enough to show a significant difference between RDPs and FDPs? This question can be answered only by recording human dive profiles during field use and documenting the outcomes. Is it possible that the authors made up their minds about RDPs and constructed experiments to support their preconception? We agree that under some circumstances RDPs can be hazardous but that has yet to be demonstrated in humans. The inapplicability of their animal study to humans is the greatest weakness of their review article.

Many models will demonstrate that for the same dives, 'deep' followed by 'shallow' will produce higher tissue inert gas tensions, and will therefore require different decompression procedures. This is reflected in standard decompression algorithms, such as the US Navy Standard Air Decompression Tables. That mirror-image RDPs demand an equal decompression obligation to FDPs is argued by default and no cogent mechanistic explanation is offered by the authors for the experimental design of their animal dives. If they imply that RDPs in a repetitive series incur the same decompression obligation as FDPs, they must reconcile their scenario with the observation that there exists no dive computer algorithm or table that would allow such profiles without significantly altering the pDCS. The experiment designed by Edmonds et al to excommunicate the workshop findings does not take into account any type of handicap in repetitive diving. Both Huggins[7] and Gerth and Thalmann[8] estimated DCS risk on profiles within the algorithms' required decompression parameters. For the repetitive dive scenario they took into account the handicap accumulated due to the previous dive (FDP or RDP). In order to maintain the same level of DCS risk in a repetitive dive, the current dive must be shorter, shallower, or start after a longer surface interval (SI).

A bubble model would prescribe the following if a diver intended to repeat a FDP series (30 msw/30 min, 15 min SI, 20 msw/30 min, 15 min SI, 10 msw/30 min) in reverse order. To keep the dive depths and bottom times constant, the surface intervals would have to be extended as follows:

- surface interval after first dive (10 msw/30 min): 90 min
- surface interval after second dive (20 msw/30 min): 120 min

These modifications would provide a predicted DCS risk that was approximately equal for FDPs and RDPs.

The authors state "*our findings suggest that multi-level and repetitive dives performed in the established forward profile manner are less hazardous than those performed in the reverse profile mode*." However, to imply that a Haldanian-based dive computer will allow hazardous profiles is incorrect and misleading.

Edmonds et al successfully tested nitrogen levels at the surface following these four profiles:

- 36 msw/30 min to 24 msw/30 min to 12 msw/30 min
- 30 msw/40 min
- 30 msw/40 min, SI 15 min, 20 msw/40 min
- 30 msw/40 min, SI 15 min, 20 msw/40 min, SI 15 min, 10 msw/40 min

Using the maximum tested surface nitrogen loading for tissues with halftimes ranging from 5 to 480 minutes thus established, we have the following things to say about the profiles that proved hazardous:

- for the RDP multi-level dive that begins with 12 msw/30 min to 24 msw/30 min, *no* remaining time was allowed for a subsequent descent to 36 msw. The study's results from 30 minutes at this depth causing 50% casualties come as not unexpected, and;
- for the RDP repetitive dive that consisted of 10 msw/40 min, SI for 15 min, 20 msw/40 min, SI for 15 min, then descent to 30 msw, only 19 min were allowed as compared to the tested 40 min that produced 33% DCS.

Thus, diving shallowest first (RDP) converts a FDP that barely requires decompression to a dive that requires much decompression, underscoring the 'practical' reasons divers perform FDPs. The question is whether the second dive, *if proper decompression is executed,* is as safe as the first dive. In this case, we would not want to venture a guess (i.e., a borderline 'no-stop dive' versus a properly executed decompression dive), but certainly to decompress the second (RDP) dive the same way as the first (i.e., 'no stop') is unsafe and not what the Workshop recommended.

Conclusion

We find no reason for the diving communities to prohibit reverse dive profiles within the no-decompression limits for dives less than 40 msw (130 fsw) and depth differentials less than 12 msw (40 fsw).

References

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They were the convenors of the Reverse Dive Profile Workshop held at The Smithsonian Institution, October 29–30, 1999.

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Drs Edmonds, McInnes and Bennett reply:

The response of Lang and Lehner to our article on "Reverse dive profiles: the making of a myth" is welcome, shedding more light as it does on the intended meaning of the Workshop recommendations.[1] We think their response makes it clear that we are in agreement about the facts. It is on the interpretation of these facts that we disagree, and the primary reason for our article was to illustrate, by documenting the statements of other delegates, that we are not alone in interpreting the final recommendations as contentious. We attempted to put the recommendations into perspective, highlighting the qualifications and doubts expressed in the proceedings of the Workshop.

Having organised and edited the Workshop, Lang and Lehner are in a position to appreciate the controversial nature of the problems of comparing the relative safety of forward dive profiles (FDP) with that of reverse dive profiles (RDP). They appreciate the limitations of the data, as described in their letter, but others who just read and accept the findings and recommendations of the Workshop may not. Interpreted literally, the recommendations indicate no increase in DCS with RDP compared to FDP, and that the no-decompression limits are the same. Lang and Lehner claim that it does not matter what the pattern of the profile is, as long as there is adequate decompression. We agree. It is axiomatic. If you decompress adequately, you are much less likely to get decompression sickness (DCS), irrespective of the profile, and without any qualification.

Our objections were not so much to the absence of evidence in either direction (safety of FDP vs RDP), but to the *implication* that the two dive profiles are equivalent. RDPs impose different decompression requirements than FDP dives. We have never proposed the prohibition of RDPs, only (like Lang and Lehner) the application of appropriate (and different) decompression. This difference in decompression obligation was unfortunately glossed over in the summarised findings and recommendations promulgated.

We believe this is the explanation for subsequent publicity in the diving literature, which we quote in our article and which uses the Workshop as authority, that dismisses the significant differences in decompression requirements between RDPs and FDPs. This interpretation is inadvertently encouraged by Lang and Lehner in their own summaries: "*There is no convincing evidence that RDP within the no-decompression limits lead to a measurable increase in decompression sickness*".[1] There is in this statement an assumption that all readers will understand that a different (and unstated) decompression requirement will operate in the two situations. We are sure this was not an intentional omission, and that the workshop participants understood this assumption very well. Perhaps so well that it seemed to be stating the obvious and did not therefore require clear elucidation.

If the recommendations stipulated that FDPs and RDPs had different decompression obligations and that one cannot extrapolate from one to the other, there would have been no need for our article. Unfortunately the Workshop is now being quoted as indicating no difference between FDPs and RDPs.

We also agree that some decompression algorithms in dive computers attempt to make allowance for an added risk with RDPs. We just do not know which ones, if any, achieve this effectively. What is needed is good experimental research to investigate the safety of a variety of algorithms. Because of the nature of the problem, we believe this is only achievable through appropriate animal models. Such models are inevitably imperfect and require extrapolation to the human experience. They are, however, superior in some respects to anecdotal reports of human diving experience where the algorithm in use is only one of the variables influencing outcome. The best assessment of safety is likely to be a synthesis of both types of investigation.

Areas in which we must agree to disagree, and which we discuss in our paper, include the historical development of the FDP recommendations, the logistics of applying the 40 metres' sea water (msw) maximum depth and 12 msw differential gradient as recommended, and the appropriateness of some of the data presented in the Workshop.

Lang and Lehner imply a plethora of new data on RDPs from scientific divers from 2000–2005, and the scrutinised monitoring of these with only a minor DCS risk. In fact, the 2005 article gives no data on RDPs and approximately two thirds of the scientific dives are at depths less than 9 msw.[2] The argument is a little circular. To support the Workshop's recommendations for the relative safety of RDPs they refer to new scientific diver data and direct us to the *SPUMS Journal* article for the data.[2] In this article there are no such RDP data and the Workshop is referenced.

We suggest another revised RDP recommendation, which complies with the data available both before and after the Workshop:

> *"RDPs have different decompression requirements to FDPs, and these requirements should be validated for both decompression tables and decompression computer algorithms before use."*

References

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Reverse dive profiles, decompression sickness, letters (to the Editor)

Letters to the Editor

Bearded ghouls and scientific meetings

Dear Editor,

With respect to Dr Harris' article in the December issue,[1] the pain from the bearded ghoul's sting appeared to be resistant to the use of hot water. I was wondering how hot the water was? My clinical experience with stings from similar fish (scorpion fish and stonefish) indicates that the temperature of the water is crucial – warm water produces no relief but hot water produces initial relief but the pain reappears as the temperature of the water decreases. However, I am the first to admit that our knowledge of the action of these venoms is only 'the tip of the iceberg' and perhaps some venoms are resistant to first-aid hot-water treatment.

I was interested in the use of a sural nerve block for pain relief. I have used this nerve block for pain relief in these injuries with great success. However, I have had to combine it with a tibial nerve block for full relief in what appears to be the area involved in the photograph; the medial side of the foot is supplied by both the sural and medial plantar (a branch of the tibial nerve) nerves, but it is a poor photograph.

Where Dr Harris' thoughts[2] on the SPUMS AGM are concerned, I agree with the Editor's reply. I note Dr Harris' opinion is based on attendance at one meeting (in 'statistical terms' expressed as n = 1). The SPUMS Committee is trying to improve the ASM but we do need participation from members to submit presentations and attend. Perhaps we can look forward to seeing and hearing from Dr Harris at future ASMs. Past onshore meetings have not been successful but this will be tested again in the future.

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References

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Key words
Envenomation, marine animals, medical society, meetings, letters (to the Editor)

Maintenance of Professional Standards (MOPS)

Dear Editor,

The following MOPS points have just been approved by the Australian and New Zealand College of Anaesthetists:

The "Introductory Course in Diving and Hyperbaric Medicine" presently held at Prince of Wales Hospital, Sydney has been approved under Code 161, Category 4 (Learning Project) for 100 CME points. The approval number for this activity is 02116 and is ongoing.

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