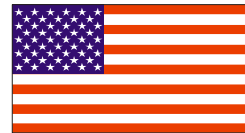


Empirical Evaluation of the Efficacy of Deep Stops in Air Decompression Dives

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INTRODUCTION

Classical decompression algorithms limit hypothetical tissue gas contents and prescribe decompressions that advance rapidly to shallow stops where most of the total stop time (TST) is allocated. Recent bubble-based algorithms limit calculated bubble profusion and size and prescribe decompressions with TST skewed toward stops deeper than those prescribed by classical decompression algorithms. NEDU has completed a controlled comparative study of these approaches.

METHODS

The methodological approach entailed comparison of DCS incidence following two air decompression dives that were identical except for the distributions of decompression stop time (Figure 1).

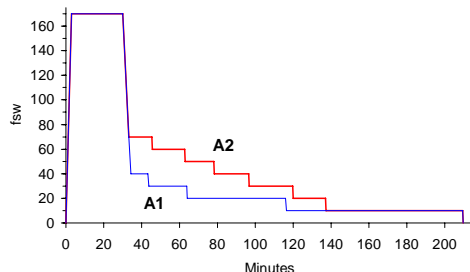


Figure 1. In both test dive profiles, divers descended at 60 fsw/min (18 msw/min) to 170 fsw (52 msw), completed a 30-minute bottom time, and decompressed on a schedule with 174 minutes TST. Ascents to decompression stops and surface were at 30 fsw/min (9 msw/min), yielding a total decompression time of 180 minutes.

Traditional Schedule (A1; blue, Fig. 1): 174-minute TST distributed among stops as prescribed by VVal-18 Thalmann Algorithm,¹ which except for use of exponential-linear kinetics, is a traditional deterministic gas content model in which decompression is prescribed by compartmental dissolved gas contents and a table of M-values or "maximum permissible tissue tensions."

Deep Stops Schedule (A2; red, Fig. 1): 174-minute TST distributed to yield minimal DCS risk according to BVM(3),² a probabilistic model of DCS incidence and time of occurrence in which DCS risk is modeled as a time integral function of compartmental bubble volumes.

• 375 man dives per schedule were planned with sequential stopping rules of reject-high if DCS risk > 7% or reject-low if DCS risk < 3%, either with 95% confidence. Stop was also planned if DCS incidence after A2 emerged as significantly greater ($P < 0.05$) than DCS incidence after A1.

- Divers wore swimsuits and t-shirts, breathed surface-supplied air via full face masks, and were immersed in 86 °F (30 °C) water in the NEDU Ocean Simulation Facility wet pot throughout each dive.
- Divers performed 115 watt cycle ergometer work at 170 fsw until 1 minute before leaving bottom, then rested during subsequent decompression.
- Divers were monitored for venous gas emboli (VGE) with trans-thoracic cardiac 2-D echo imaging (Siemens Medical Solutions® Acuson Cypress Portable Colorflow Ultrasound System) at 30 minutes and 2 hours postdive.
- A detailed human-use protocol for the study was reviewed and approved by the NEDU Institutional Review Board.

RESULTS

The trial was terminated after midpoint interim analysis when 81 divers had completed 390 man-dives. Neither schedule was rejected (Figure 2), but DCS incidence in Schedule A2 (deep stops, 11 DCS/198 dives) was significantly higher than in Schedule A1 (3/192, $p=0.030$, one-sided Fisher Exact), see Figure 3.

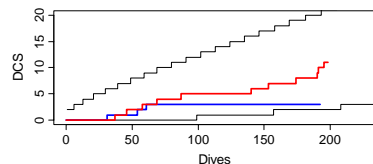


Figure 2. Sequential trial envelope (black lines) and cumulative DCS on Traditional (blue) and Deep Stops (red) schedules

BRIEF CASE DESCRIPTIONS

Traditional - VVal-18

1. Knee pain (1/10), presented next morning
2. Shoulder pain (3/10), weakness, paraesthesia, 2 h postdive
3. Knee pain (1/10), presented next morning

Deep Stop - BMV(3)

4. Elbow pain (2/10), presented next morning
5. Cutis marmorata, 1 h 45 min postdive
6. Shoulder pain (3/10), 3 h 30 min postdive
7. Disorientation, vertigo, nausea, 15 min postdive
8. Cutis marmorata, 3 h postdive
9. Shoulder pain (5/10), 5 h 30 min postdive
10. Shoulder pain (4/10), 4 h 30 min postdive
11. Shoulder pain (3/10), 3 h 30 min postdive
12. Knee pain (3/10), 13 h 30 min postdive
13. Syncope, tunnel vision, 2 min postdive
14. Hand pain, finger numbness, 27 h postdive

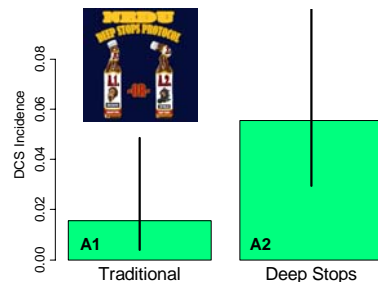


Figure 3. Observed DCS incidences (mean, 95% CI) for the two test dive profiles. (All 14 DCS cases are included.)

On review, one Schedule A2 DCS was excluded (#13 in Brief Case Descriptions), but the result remained significant ($p=0.047$). Most DCS was mild, late onset (mean 9, SD 8 hours, $n=11$), Type I, but two cases involved progressing CNS manifestations.

The association between DCS occurrence and maximum observed intravascular bubble grade is illustrated in the receiver-operator characteristic (ROC) curve shown in Figure 4. High VGE grades were relatively insensitive and nonspecific indicators of DCS, with area under the ROC curve (AUC) only slightly greater than the no-discrimination value of 0.5.

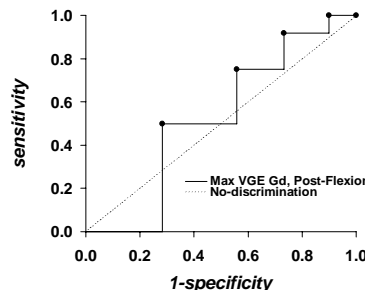


Figure 4. ROC curve for association of DCS occurrence with maximum observed VGE grades. Points graduate with increasing false positive rate (1-specificity) in order: VGE grades IV, III-IV, II-IV, I-IV, and 0-IV. AUC=0.68.

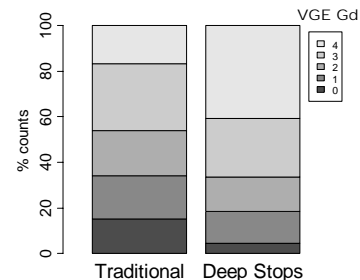


Figure 5. Maximum VGE grade of all exams.

Despite the poor overall association between DCS and VGE, median VGE scores (maximum at rest and after limb flexion) were significantly higher after Schedule A2 than after Schedule A1 (Wilcoxon rank sum test, $W=12967$, $p<0.0001$), see Figure 5.

VGE scores at the 2-hour exam were increased over those at the 30-minute exam after Schedule A2 (Wilcoxon rank sum test, $W=4418$, $p=0.0006$) but not after Schedule A1 (Wilcoxon rank sum test, $W=2578$, $p=0.734$)

CONCLUSIONS

The deep stops schedule had a greater risk of DCS than the matched conventional schedule.

Slower gas washout or continued gas uptake offset benefits of reduced bubble growth at deep stops.

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