COMPARISON OF V-4 AND V-5 EXERCISE/OXYGEN PREBREATHE PROTOCOLS TO SUPPORT EXTRAVEHICULAR ACTIVITY IN MICROGRAVITY

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INTRODUCTION

- Extravehicular activity (EVA) from the International Space Station requires decompression from a standard of 14.7 psi ambient pressure to work in a 4.3 psi extravehicular mobility unit (EMU or spacesuit)
  - A 4 h resting oxygen prebreathe preceding decompression was used to eliminate inert gas and avoid decompression sickness (DCS)
- The Prebreathe Reduction Program (PRP) incorporated exercise during oxygen prebreathe to attempt to reduce the necessary prebreathe time
- Initial testing produced a protocol (Phase II) incorporating ergometry exercise during 120 min of oxygen breathing and 30 min at 10.2 psi where subjects breathed 26.5% nitrox during a simulated suit donning period
  - 10 min at 75% peak oxygen consumption ($VO_{2\ peak}$) followed by 40 min intermittent light exercise (ILE), then 50 min of rest
    - Oxygen consumption (VO_2) during ILE was estimated in separate trials to approximate 5.8 $mL \cdot kg^{-1} \cdot min^{-1}$
  - Testing yielded 0 DCS / 45 person-exposures
- The Phase II protocol was approved for operations and has been used on 42 EVAs, providing significant time savings compared to the standard 4 h resting oxygen prebreathe
- The Phase V effort focused on developing a light exercise protocol that could be carried out within the spacesuit, eliminating the need for an exercise ergometer

METHODS

- Two oxygen prebreathe protocols were tested sequentially in Phase V:
  - **V-4** - 160 min prebreathe with 150 min of continuous ILE
    - Entire protocol was completed at 14.7 psi
    - Total VO_2* 905 $mL \cdot kg^{-1}$; all upper body exercise
    - Exercise continued until just prior to decompression to 4.3 psi
  - **V-5** - 160 min prebreathe with 140 min of ILE
    - Protocol included transient depressurization to 10.2 psi
      - First 40 min at 14.7 psi, then 30 min at 10.2 psi (breathing 26.5% oxygen) after a 20 min depress, simulating a suit donning period
    - Total VO_2* 863 $mL \cdot kg^{-1}$; 51% upper body / 49% lower body exercise
    - 50 min of rest preceded decompression to 4.3 psi
  - *Note: VO_2 for both V-4 and V-5 characterized in separate trials
- Following the initial stages described above, both protocols required subjects to perform 50 min of lower body ILE, followed by 50 min rest before decompression to 4.3 psi (altitude equivalent of 30,250 ft [9,220 m])
- Protocol accept/reject criteria
  - Accept if DCS ≤15% and Grade IV (1) VGE ≤20% (minimum 50 trials)
  - Reject if DCS >15%, Grade IV VGE >20% or any neurological DCS
- Differences in DCS and VGE incidence were assessed through non-parametric Fisher Exact test statistics
  - Significance accepted at p<0.05

Suit simulator set up for multiple semi-recumbent intermittent light exercise simulating astronaut tasks

Suit simulator set up for leg ergometry

Activities guided by electronic taskprompter

RESULTS

- Summary data and statistical contrasts provided in Table 1 and Figure 1
  - Note: abstract submitted with V-4 testing complete (3 DCS/6; rejected) and V-5 testing at 0 DCS/11 person-exposures (trials ongoing) (Fisher Exact p=0.029)

Table 1. Summary data and statistical contrasts*

Protocol	Completed Person-Exposures	DCS		VGE - Grade IV		VGE - Non-Zero	
		Count	%	Count	%	Count	%
V-4	6	3	50.0	1	16.7	3	50.0
V-5	24	1	4.2	3	12.0	6	24.0
Fisher Exact Test		p=0.016		p=0.439		p=0.118	

* Note: VGE contrasts computed on V-5 n=25 since one subject-exposure ended prematurely (asymptomatic, but with Grade IV VGE) due to observed presence of bubbles in left heart

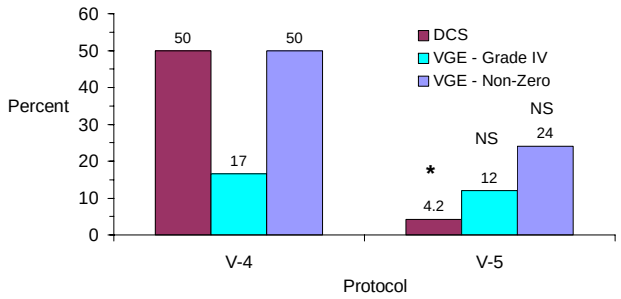

Figure 1. Percent of DCS and Grade IV VGE in V-4 and V-5 protocol trials (statistical contrasts between protocols: * = p<0.05; NS = non-significant)

DISCUSSION

- The Phase V-5 protocol was designed to be as close as possible to the Phase II protocol; it had several features not found in the V-4 protocol:
  - Use of an depressurization to and 30 min stay at 10.2 psi, followed by repressurization to 14.7 psi
  - Additional lower body exercise
  - A 50 minute period of post-exercise rest prior to ascent to final spacesuit pressure (4.3 psi)
- The V-5 protocol produced significantly less DCS than the V-4 protocol despite a 5% lower total oxygen consumption in V-5
  - 863 vs. 905 $mL \cdot kg^{-1}$
  - Factors other than total oxygen consumption are necessary to explain these observations
- Logistic regression analysis of all Prebreathe Reduction Program data shows that both the 10.2 psi depress/repress and post-exercise rest significantly improve model predictions and reduce decompression stress
  - These observations suggest involvement of a gas phase or nucleation-related mechanism beyond inert gas elimination kinetics

POTENTIAL APPLICATIONS

- If ultimately accepted and approved for flight, the V-5 protocol will provide an exercise prebreathe protocol that does not require an ergometer, and that will save 45 min in comparison with the existing ergometer-based exercise prebreathe protocol

CONCLUSIONS

- The V-5 protocol produced significantly less DCS than the V-4 protocol during human trials in a hypobaric chamber
- The data suggests that these differences could be attributable to a gas phase or nucleation mechanism, although the use of lower body exercise is a confounding variable
  - Trials will continue until point of acceptance or rejection is reached

REFERENCES

1. Spencer MP, Johanson DC. Investigation of new principles for human decompression schedules using the Doppler blood bubble detector. Office of Naval Research Tech Rep ONR Contract N00014-73-C-0094. Seattle, WA: Institute for Environmental Medicine and Physiology, 1974.