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Potential for Reduction of Decompression Sickness By Prebreathing With 100% , Oxygen While Exercising .

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Potential for Reduction of Decompression Sickness By Prebreathing With 100% Oxygen While Exercising

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ABSTRACT

Exercise performed for at least 30 min while prebreathing 100% oxygen prior to decompression has been reported to increase efficiency of denitrogenation by 100-500%. The incidence of decompression sickness following such a prebreathe was decreased by 50% compared to resting prebreathe. If prebreathing with exercise is to have an operational application, it must be brief, it must significantly reduce standard prebreathing times, it must not create excess fatigue, and it must use exercise equipment compatible with aerospace operations. This article provides background and recommends parameters for a test to determine the operational feasibility of prebreathing with exercise.

DENITROGENATION PRIOR TO DECOMPRESSION by prebreathing with 100% oxygen has been studied extensively and found to be an effective means of reducing or eliminating the incidence of decompression sickness (DCS) (3,6,12,15,23, 26). Prebreathing for up to four hours to avoid or reduce the incidence of DCS is an essential and standard operational procedure before exposure to low pressures during extravehicular activity (EVA) and to protect against DCS should inadvertent decompression occur during high-altitude reconnaissance flights. Time-consuming DCS preventive measures interfere with efficient utilization of the crew's time by reducing the productive portion of their fixed-length work day and delaying the start-time of their efforts. The optimal solution would be the development of pressure suits to satisfy the requirements of mobility, comfort, and function while, at the same time, maintaining a sufficient pressure differential to avoid the possibility of DCS. Until such suits become available for both high-altitude and space operations, other alternatives must be investigated.

If the efficiency of the denitrogenation process could be enhanced, the time spent prebreathing could be reduced. Experimental evidence showing substantial reduction in prebreathing time, with no increase in incidence of DCS, would provide justification for a change in operational decompression procedures. However, prebreathing time would have to be reduced enough that crewmembers could prebreathe as little as 15 min. They would then don a pressure suit and immediately depart for the aircraft to complete normal operations before takeoff while continuing to prebreathe in the sealed pressure suit. The prebreathe normally accomplished prior to takeoff for high altitude reconnaissance missions that includes donning a pressure suit prior to prebreathe, would thus be significantly shortened, providing an operational savings of time.

If the current 3-4 h prebreathing time prior to EVA could be significantly shortened by an enhanced denitrogenation procedure, considerable enhancement of mission effectiveness would result. A reduced prebreathing time would also allow safer and more timely response of astronauts to emergency situations requiring EVA.

BACKGROUND

Increasing the time of prebreathing, hence increasing the elimination of nitrogen from the body, has been shown to decrease the incidence of DCS (12,15,21,23). The rate of nitrogen exchange between the body and the breathing environment has long been recognized as being directly dependent upon the rate of blood flow and the solubility of nitrogen per unit mass of tissue (11). Later work supported this concept with reports indicating that the rate of denitrogenation is a specific function of cardiac output and blood-tissue perfusion rate (3,4,18,19).

Since skeletal muscle accounts for about 40% of the body, a large increase in blood flow to skeletal muscle enhances the rate of muscle denitrogenation. Strenuous exercise can increase blood flow to skeletal muscle by more than 20-fold by stimulating cardiac output and opening muscle capillaries. Therefore, it follows that one possible means of increasing efficiency of denitrogenation and thereby reducing DCS is to increase the cardiac output and blood-tissue perfusion rate by exercising while prebreathing. Indeed, a large majority of previous reports have indicated that exercise performed while prebreathing 100% oxygen prior to decompression increased the efficiency of denitrogenation (1,5,10,24) and decreased the incidence of DCS (1,24).

A problem may exist due to the possible formation of bubbles by cavitation during exercise prior to decompression. These bubbles could conceivably enlarge during decompression and increase DCS symptoms. However, the concern of bubble formation appears to be unwarranted. Harvey et al. (17) reported that air and nuclei fail to pass the pulmonary capillaries, thus documenting a mechanism for disposal of any bubbles formed during exercise prior to decompression. In addition, Balke (1) found that mild to severe exercise performed by 6 subjects breathing ambient air did not significantly increase the susceptibility for DCS during ascents to 38,000 ft (11,582 m) 10 min after the exercise.

Bigelow et al. (8) used several physiologic parameters of exercise in developing their mathematical models of DCS. They reasoned that exercise: 1) raises body temperature; 2) increases cardiac output; 3) alters the respiratory quotient; and 4) changes the rate of oxygen consumption. An increase in body temperature was studied by Balldin (2), who found that indeed an increase in environmental temperature elevated nitrogen elimination. Since exercise also produces heat, muscle peripheral vasodilation occurs to dissipate heat, provide additional oxygen and reduce buildup of carbon dioxide. A concurrent increase in blood flow to subcutaneous layers of fat tissue has also been suggested (2).

Balke (1) found that 7 subjects breathing 100% oxygen, eliminated an average of 640 cc of nitrogen in 60 min of rest which increased 146% with mild exercise. However, his (1) decompression experiments showed a less dramatic improvement in tolerance to DCS, leading him to conclude that exercise was only mildly effective. His exercise level was about 8.75 ml oxygen/kg.min, which approximates only 2.5 times resting oxygen consumption (9). This level is probably too low to cause sufficient changes in cardiac output, circulation, and ventilation rate necessary to enhance denitrogenation enough to affect DCS. Earlier researchers, also using

low levels of exercise, reported similar results; a significant enhancement in denitrogenation (5,14) and either a reduction in DCS (14) or no effect on incidence of DCS (16). Since the exercise types, exercise levels, prebreathing times, and severity of exposures used in these studies have varied so much, specific comparisons are unwarranted (13).

The exercise levels in the article by Webb et al. (24) were much greater than those described by other authors. The subjects "either jogged in place for the entire half-hour, or else sprinted vigorously in place as frequently as possible during the half-hour." We estimate this level of exercise to be well over 60% of maximal oxygen uptake. They found that one h of prebreathing with this level of exercise during the first half hour significantly reduced rates of limb bends (Type I DCS) (24). However, this level and duration of strenuous exercise may be too fatiguing while prebreathing, and their equipment limitations due to a high ventilation rate reduced operational practicability.

PROPOSED STUDY

We believe that the definitive experiments have not been conducted in developing the operational use of exercise while prebreathing 100% oxygen. Therefore, we plan to conduct research based on a short prebreathing time as determined by the requirements of high-altitude and space operations. We plan to accomplish this goal with exercises that include the upper body and use improved breathing and exercise equipment.

These exercises should produce almost 100% denitrogenation in the faster tissues within about 15 min. Rapid denitrogenation of the faster tissues will enhance more rapid release of nitrogen from adjacent slower tissues due to the favorable diffusion gradient. A residual effect of this short, intense period of exercise is enhanced denitrogenation for at least 30 min after the exercise is completed due to continued increases in ventilation and tissue-blood perfusion rate. Thus, the period of time between completing the strenuous exercise and completing ascent to operational altitudes would provide additional denitrogenation to reduce the DCS incidence.

We propose the level of exercise during prebreathe to be at least 70% of each subject's maximal oxygen uptake. This level is supported by the research of MacDonald and Pilmanis (20) who found that at "approximately 60% of the maximal oxygen uptake and greater, the ventilatory drive was sufficient to increase ventilation and reduce alveolar carbon dioxide pressure" to below 50 mmHg. Our study, using a 10-15 min period of prebreathing while exercising, would reduce

the fatigue level observed during an earlier study (24), shorten recovery times, and reduce prebreathing time to meet operational requirements.

We will use exercise equipment during the prebreathe period that is compatible with aerospace operations. Since these exercises will be performed in space, they must be able to be performed in a weightless environment. We will incorporate individual levels of fitness, stature, and strength to ensure that consistent levels of exercise are used for each subject. Our exercise equipment will be credible as a research tool that will measure work load and level of effort. We will also consider the availability of space for the exercise equipment in the operational environment.

We plan to use exercise equipment such as an arm and leg cycle ergometer or Versa-Climber to provide the necessary balance and intensity of upper and lower body exercise (7). Determination of blood lactate levels before, immediately after, and up to 5 min post-exercise will be accomplished to establish an objective measure of the level of exercise attained by each subject.

Testing the influence of the selected exercise on the incidence of DCS will be accomplished at a hypobaric chamber pressure of operational significance to high-altitude and space missions. The study will have two control exposures with standard 100% oxygen prebreathe at rest for: a) 1 h and b) a shortened prebreathe period equivalent to the prebreathe period with exercise. Nitrogen elimination during prebreathing periods will be quantified using a mass spectrometer. Bubble detection using Doppler ultrasound (22) will be used to provide additional indications of prebreathing effectiveness.

Crewmembers exposed to decompression during normal operations continue to perform tasks which require mental and physical work. Since these activities are distractions which may delay recognition of DCS symptoms, our subjects will be required to perform types of exercises and have mental distractions during their decompression exposures to closely simulate the operational environment. Exercises performed in our previous efforts (25), while watching action-oriented videos, will be used in these studies. Since crewmembers are not queried regularly by controllers as to their physical well-being, our subjects will be treated in a similar manner.

In summary, previous studies limited the operational practicability of exercise-enhanced denitrogenation to reduce DCS by using extended prebreathing times and intensities of exercise which did not achieve acceptable results. Our study will use the parameters discussed in this article to test the efficacy of short-term, strenuous exercise while prebreathing 100% oxygen to

significantly reduce DCS during exposure to low environmental pressures.

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