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Altitude DCS Research in Support of Special Operations Forces (SOF)

Andrew A. Pilmanis, Ph.D., and James T. Webb, Ph.D.

Air Force Research Laboratory, 2504 Gillingham Dr., Suite 25, Brooks AFB, TX 78235, USA

The potential impact of altitude decompression sickness on special operations missions may manifest primarily in high altitude airdrop operations and operations using unpressurized aircraft such as AC-130 and the CV-22 Osprey. Research at AFRL, Brooks AFB on altitude DCS has for many years produced findings directly applicable to SOF mission scenarios. This paper summarizes 3 areas of research with current applicability. Complete publications are in preparation and the results presented here should be considered preliminary.

1. THE EFFECT OF REPEATED ALTITUDE EXPOSURES ON THE INCIDENCE OF DECOMPRESSION SICKNESS (DCS)

Repeated exposures to reduced pressure are inherent to airdrop training operations, chamber training, and flying operations in unpressurized aircraft. Timely conduct of these activities requires that the personnel not be exposed to significant risk of decompression sickness (DCS) because symptoms may result in interference with or termination of operations. Treatment which could delay further training is also an impediment to effective scheduling and represents significant cost.

During any altitude exposure, the decompression is accomplished from full nitrogen saturation at ground level pressure to a lowered pressure, where gas emboli may be created. The preoxygenation prior to decompression reduces the supersaturation in "fast" tissues, i.e. tissues that take up or eliminate nitrogen rapidly. However, the slower tissues such as bone, ligaments, and tendons do not denitrogenate as quickly during preoxygenation. Thus, each repeated altitude decompression eliminates successively more nitrogen, particularly if the breathing gas remains 100% oxygen during any recompression-decompression sequence.

There exists a potential for uptake of nitrogen during an air-breathing, ground-level break between altitude exposures. If the uptake allowed addition of nitrogen to gas emboli formed during the previous decompression, the effect could be one of increased DCS risk due to increased gas emboli size during the next decompression. The elimination of inert gas starts during the decompression and the fast tissues will be eliminated first followed by the slow tissues. The slow tissues may take a very long time to eliminate inert gas. The altitude exposure is, however, followed by recompression to ground level pressure, which may decrease or eliminate the already existing bubbles. If bubbles still exist at ground level, they may expand during a succeeding hypobaric exposure and cause symptoms of DCS.

Knowledge of the threshold for repeated altitude exposure effect on DCS incidence or severity could be helpful in:

- planning for high altitude reconnaissance operations
- manning and scheduling of inside observers for USAF training chamber operations
- scheduling of airdrop pilot training which involves moderate to high altitudes
- scheduling of training and operational multi-sortie gunship missions

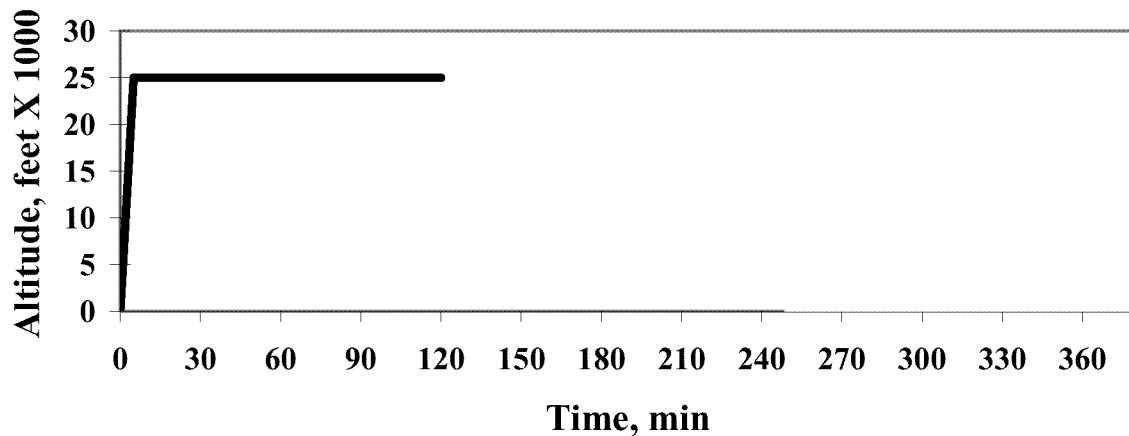
Such knowledge may also benefit technology transfer to civilian pilot education and procedural guidelines.

Inconclusive data are available concerning the question of repeated decompression effect on DCS (1, 3, 4, 5, 6, 7, 8, 9). Specific to SOF, Butler in 1991 (2) described a case of DCS presented as optic neuropathy, which he believed could be attributed to repeated parachuting decompressions. Operationally, it is assumed that there is a detrimental effect of repeated altitude decompressions on DCS risk and, therefore, various ground interval requirements between flights have been imposed. The origin of this

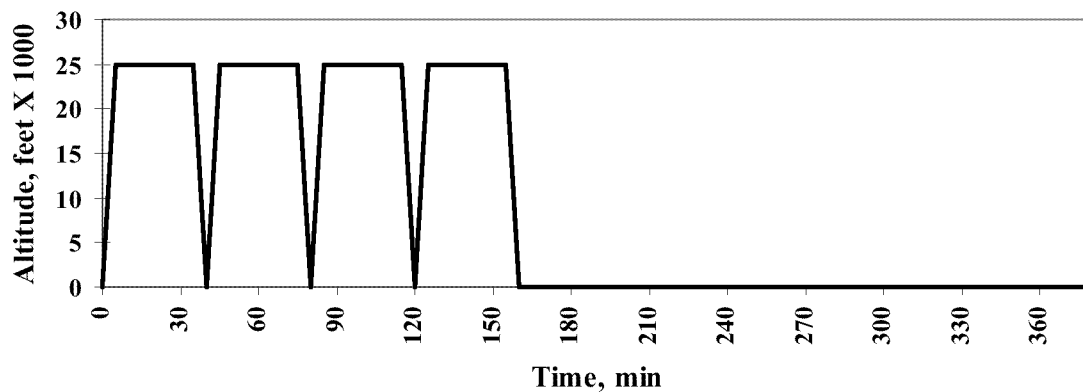
assumption has been the observation that many of the DCS cases occur late in the day. A typical day might include 5+ parachute jumps.

Thirty-two research subjects were exposed to the 3 profiles pictured in Figure 1. Condition A consisted of one, 2-hr exposure to pressure corresponding to an altitude of 25,000 ft, with no preoxygenation. Condition B consisted of four, 30-min exposures to the same simulated altitude, and with zero time at ground level in between and no preoxygenation. Condition C consisted of four, 30-min exposures to the same simulated altitude, but with 1-hr ground level interval breathing air. At altitude, the subjects performed four sets of mild exercises each hour. They consisted of turning a crank by hand for 4 min, operating a wrench each 5-10 s for 4 min, and pulling a rope with alternating hands with a resistance of 7.7 kg (17 lbs.) for 4 min. Precordial echo-imaging/Doppler monitoring was accomplished with an HP SONOS 1000 Echo-Imaging System after each exercise sequence to provide information on development of venous gas emboli (VGE).

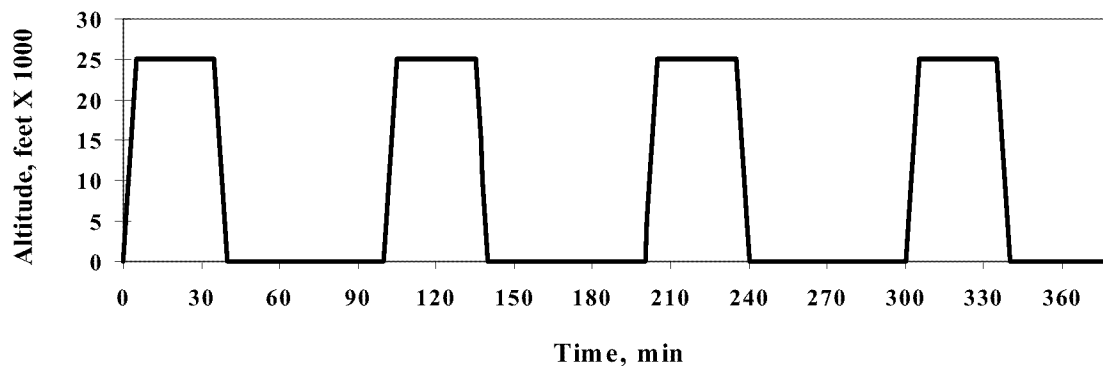
Figure 1. Exposure profiles



A. One, 2-hour exposure, zero-preoxygenation



B. Four, 30-min exposures, zero time at ground level, zero-preoxygenation



C. Four, 30-min exposures, 1-hour ground level interval on air, zero preoxygenation

The results are presented in Table I and Figures 2 and 3. In condition A, with 2 hr continuous hypobaric exposure at 25,000 ft, 59% DCS occurred. In conditions B (four, 30-min altitude exposures with no ground time in between) and C (four, 30-min altitude exposures, but with a 1-hr ground level interval breathing air) 22% and 6% DCS occurred respectively. Both conditions were significantly different from condition A ($p < 0.05$). The mean onset time for DCS was longer for condition A than for both conditions B and C.

Exposure	DCS Incidence %	DCS Onset (min)	VGE Incidence %	VGE Onset (min)
A (control)	19 cases (59%)	70 ± 7	28 cases (88%)	32 ± 5
B	7 cases (22%)*	54 ± 10	21 cases (66%)	40 ± 8
C	2 cases (6%)*	40 ± 13	21 cases (66%)	43 ± 8

TABLE I. Incidence of DCS and VGE and onset time of DCS and VGE are given for the three conditions A, B and C.

VGE occurred in 88% in condition A, but only in 66% for both of the conditions B and C (B and C were significantly different from A, $p < 0.05$). The mean onset time of VGE was not significantly different the three conditions. Condition A resulted in 4 cases of serious respiratory/ neurological symptoms, while condition B only had one and condition C had none. All other cases involved pain, paresthesia, and/or skin symptoms. All symptoms resolved during recompression to ground level.

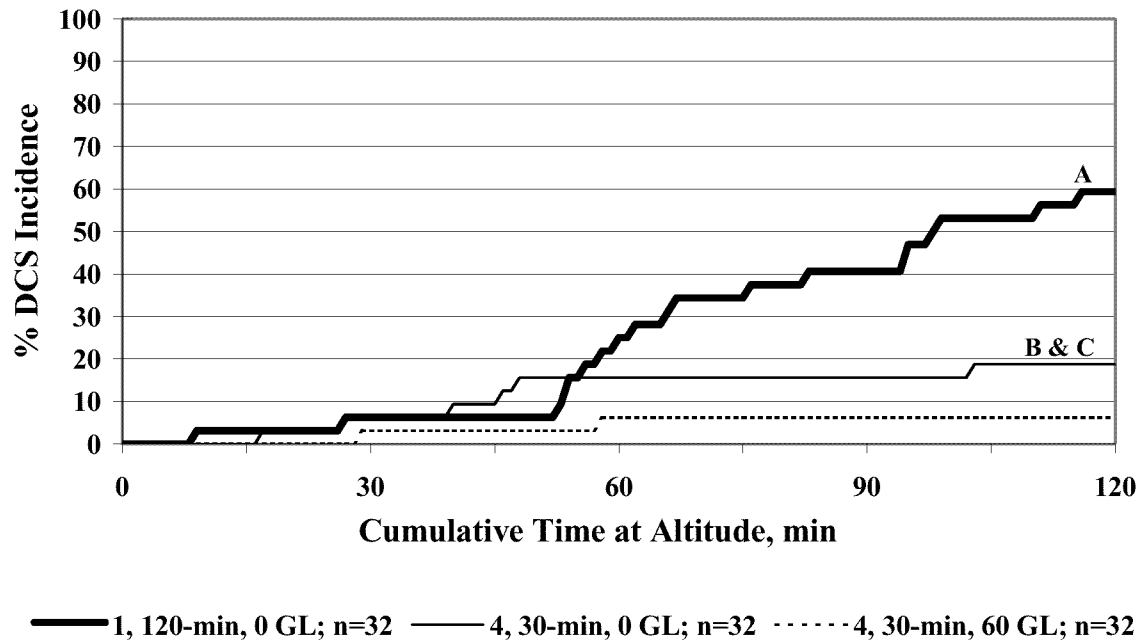


Figure 2. The percentage of cumulative DCS incidence plotted versus cumulative time at altitude for the three conditions A, B and C.

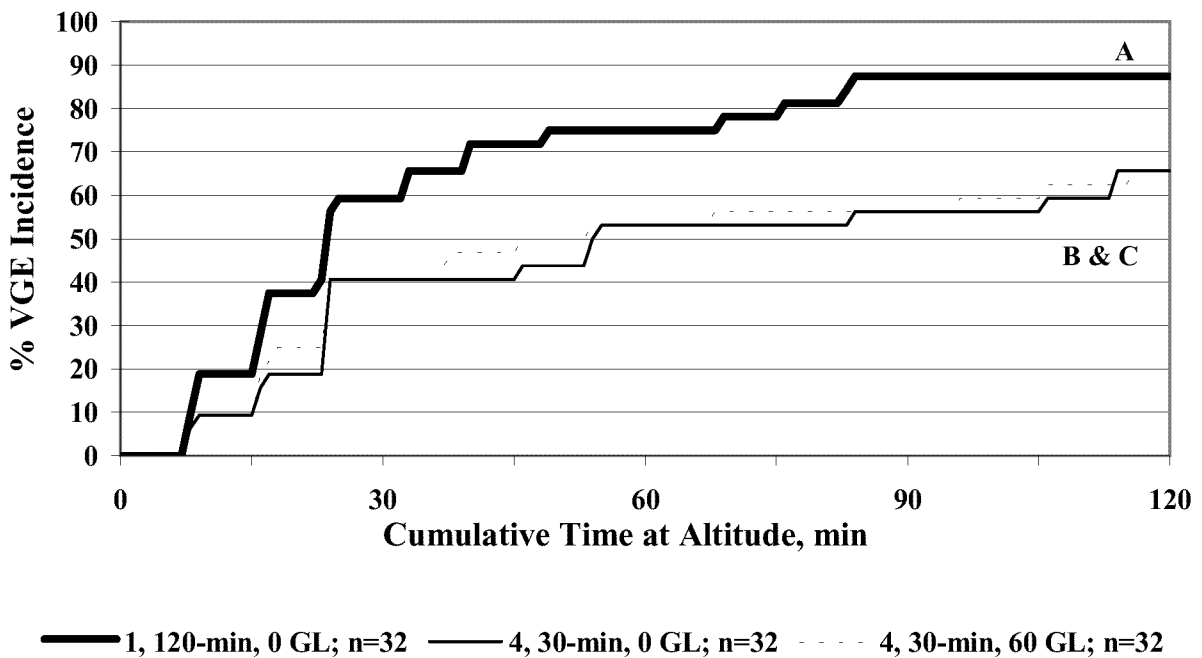


Figure 3. The percentage of cumulative VGE incidence plotted versus cumulative time at altitude in the conditions A, B and C.

This study indicates a decreased risk of DCS with multiple short flights both without ground level intervals and with 1 hour air-breathing intervals, than with a single continuous flight of equal time duration.

2. POST-LANDING EXERCISE AND RISK OF DCS IN HIGH ALTITUDE PARACHUTE

Special Operations Forces employment of high altitude airdrop in the execution of the insertion phase of their missions involves altitude exposures that pose a risk of developing decompression sickness (DCS) symptoms. Moderate to heavy exercise performed immediately after landing may further increase the incidence and severity of DCS and could become a serious factor in mission success or failure. The mission impact of DCS symptoms developed after landing is unknown. SOF teams should not be faced with a situation where a **preventable** decrement in performance affects the accomplishment of the mission or survival of the team. The mental and physical fitness required for these missions is very high and any decrement in performance due to pain or other DCS symptoms needs to be quantified and recommendations offered for protection from DCS symptom development. Since reviews of DCS research are silent about post-exposure exercise effects on DCS incidence and severity (10,12), no scientific basis exists for determining the effect of such activity. However, AFI 11-403 (7.2.1; 1 Dec 96) and AFP 160-5 (16-3; 23 Jan 76) contain post-flight restrictions for personnel who take part in chamber flights: "No physical exercise, strenuous or extended duty for a period of 12 hours." Such a restriction is not compatible with SOF missions involving high altitude exposures.

In this on-going study, 120 subjects are scheduled to complete one exposure each. The target population (SOF) is highly fit (top 5% of general population's aerobic capacity) and matching that subset with an identically-fit subset of subjects is impractical due to availability of such subjects. However, subjects were able to pass the USAF fitness test, which placed them in the top 50% of the general population's aerobic capacity. The subjects completed a maximal exercise test to establish the level of post-exposure exercise to be accomplished.

The exposure/testing scheme (Figure 4) involves exposures predicted to result in approximately 50% decompression sickness (DCS) followed by post-exposure rest or exercise (Test). The reason for using an altitude exposure which is predicted to yield 50% DCS was to yield a wide range of reactions which provided a diverse set of reactors subjected to the next stressor, post-exposure exercise. As the subjects reached ground-level pressure, they were randomly selected to perform rest or exercise. The control, resting post-exposure activity consisted of 2 hours of seated rest. Half of the subjects served as controls, resting post-exposure activity, and half performed strenuous dual-cycle ergometry simulating post-landing activity during the same period of time. One resting control and one exercising test accomplished after identical altitude exposure conditions and DCS results become a matched test for statistical purposes. The post-exposure exercise was accomplished in three sets of approximately 15 minutes each at approximately 50% of $\text{VO}_{2\text{peak}}$ over a period of 2 hours after the altitude exposure.

Figure 4. Exposure/Testing Scheme

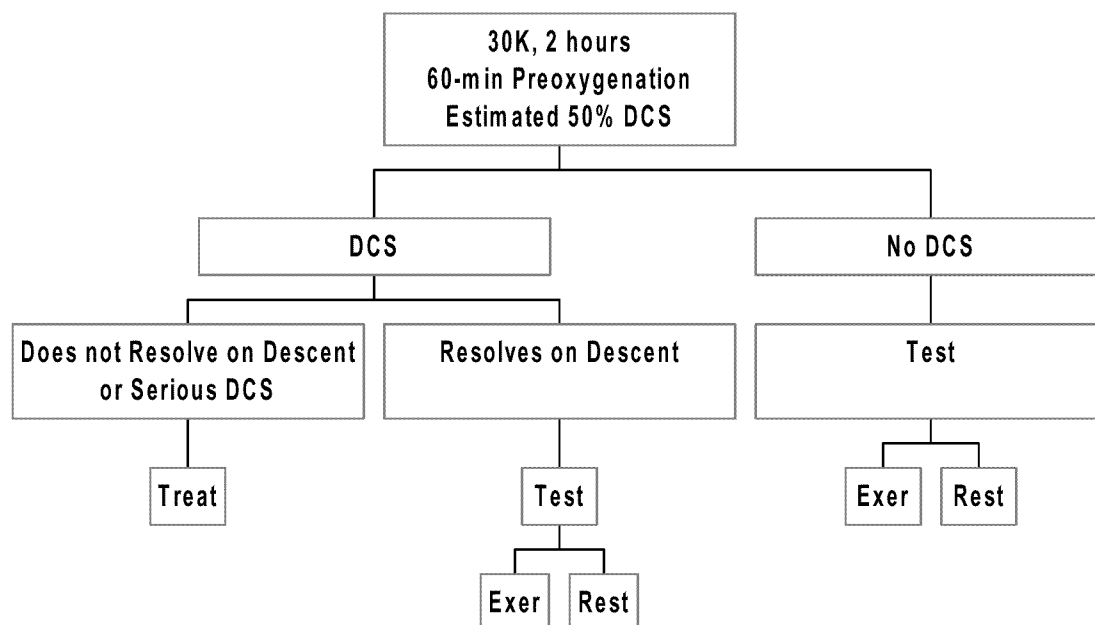
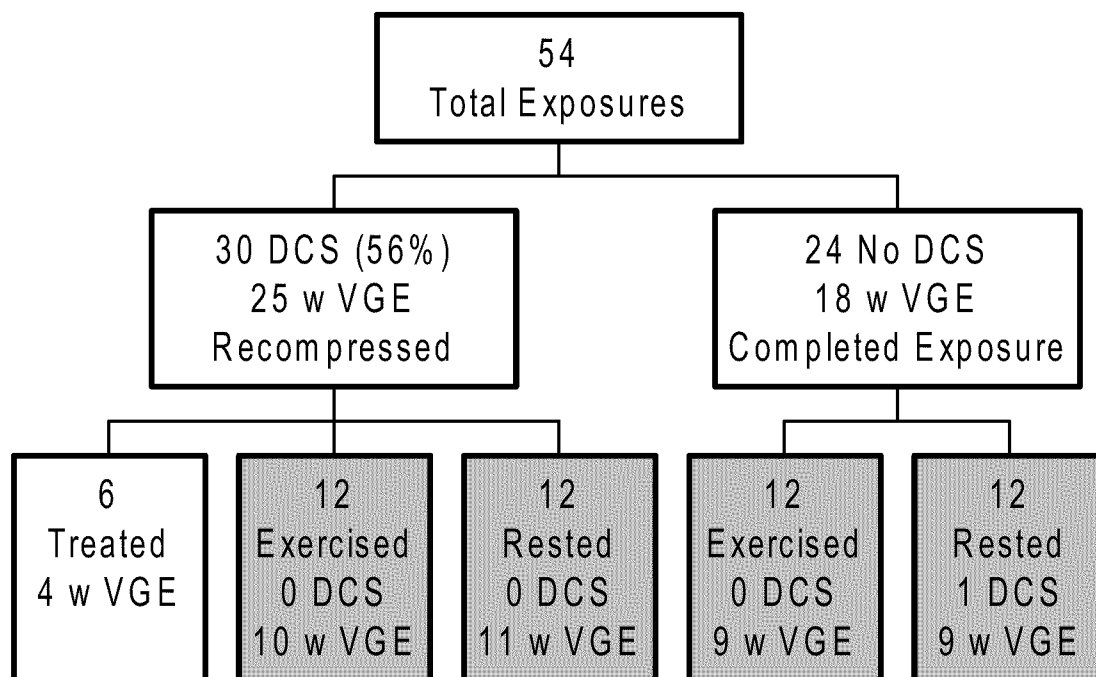


Figure 5. Preliminary results



It is too early in the study to draw conclusions since less than half of the exposures have been completed. However, the preliminary results in Figure 5 are of great interest to SOF. Post-flight exercise has resulted in NO DCS symptoms. The control (resting) has resulted in one case of post-flight DCS.

3. THE EFFECT OF EXPOSURE TO 35,000 AND 40,000 FT ON THE INCIDENCE OF ALTITUDE DECOMPRESSION SICKNESS

The potential for development of altitude DCS during high altitude airdrop missions conducted by the USAF has been largely avoided by restricting time of exposure and requiring preoxygenation. For example, airdrop from 35,000 ft requires 75 min of preoxygenation and exposure time limited to 30 min. An airdrop is dependent on many factors; e.g. weather, aircraft and personal equipment, and mission timing. Variation in these and other factors could delay the airdrop following decompression of the aircraft and extend the duration of exposure. It would benefit the airdrop community to know the change in DCS risk caused by extending the exposure time beyond 30 min.

One of the variables in determining DCS risk is the activity level of individuals involved in the mission; e.g. aircrew in the cockpit, loadmasters coordinating the airdrop, and the jumpers. Level of exercise is of considerable importance in determining DCS risk (14,15). Ferris et al. (11) found that seated rest at 35,000 ft without preoxygenation was as effective at preventing DCS as 2 h of preoxygenation prior to an exercising exposure to 35,000 ft. A 4-h preoxygenation provided protection for 10 of 12 subjects exposed to 35,000 ft while exercising. In another test with 7 exercising subjects at 35,000 ft, eight h of preoxygenation provided complete protection from DCS (11). Fulton (12) reviewed the effects of rest versus exercise (five deep knee bends every 3 min) during zero-prebreathe exposures to 35,000 ft and showed 55% DCS incidence in 90 resting subjects and 100% DCS in 158 exercising subjects. The mean time to DCS in that study was 61 min while at rest and 16 min while exercising. With four h of prebreathe, the incidence of DCS was reduced to 55% in the exercising group.

The current study provided information on risk and effect of exercise using the current criteria for declaration of DCS symptom existence. Data on venous gas emboli (VGE) were unavailable during the WWII studies because the equipment for non-invasive measurement of VGE was not developed until the 1970s. During the current study, the data on VGE were collected to determine relative exposure severity in

addition to observed or reported DCS symptoms. The information provided by this study could be used to verify or recommend changes to existing Air Force policy.

Prior to each 3-h altitude exposure, a physician conducted a short physical examination of subjects to identify any signs of illness or other problem that would endanger the subject or bias the experimental results. Chamber ascent and descent were at a rate not exceeding 5,000 fpm from ground level pressure to 20,000 ft and at a rate not exceeding 10,000 fpm from 20,000 ft to 35,000 ft.

At 10-15 min intervals, the subjects were monitored for VGE using a Hewlett Packard Sonos 1000 Doppler/Echo-Imaging System. This system permits both audio and visual monitoring and recording of gas emboli in all four chambers of the heart.

Subjects were either seated at rest for the entire exposure or performed strenuous or mild exercise at intervals throughout the exposure. The strenuous exercise consisted of cycle ergometry at 60 rpm for 3 of every 10 min with a resistance of 2kp. Walking to the Monarch 818E ergometer and echo-imaging station between periods of seated rest involved less than ten steps in any direction. Mild exercise consisted of three upper-body exercises. Thirty male and thirty female subjects performed strenuous exercise during one exposure and remained seated at rest for a second exposure, allowing matched controls for the effect of strenuous exercise. Thirty-two different subjects were used for the exposures involving mild exercise.

The DCS incidence with strenuous exercise was not significantly different (Chi Square = 0.54; $P = 0.47$) than that with mild exercise (Fig. 6). DCS symptoms occur more rapidly with mild or strenuous exercise compared with symptom onset during rest ($P < 0.0001$; Fig. 6). The same statistical result was found with comparisons of incidence and onset time of VGE.

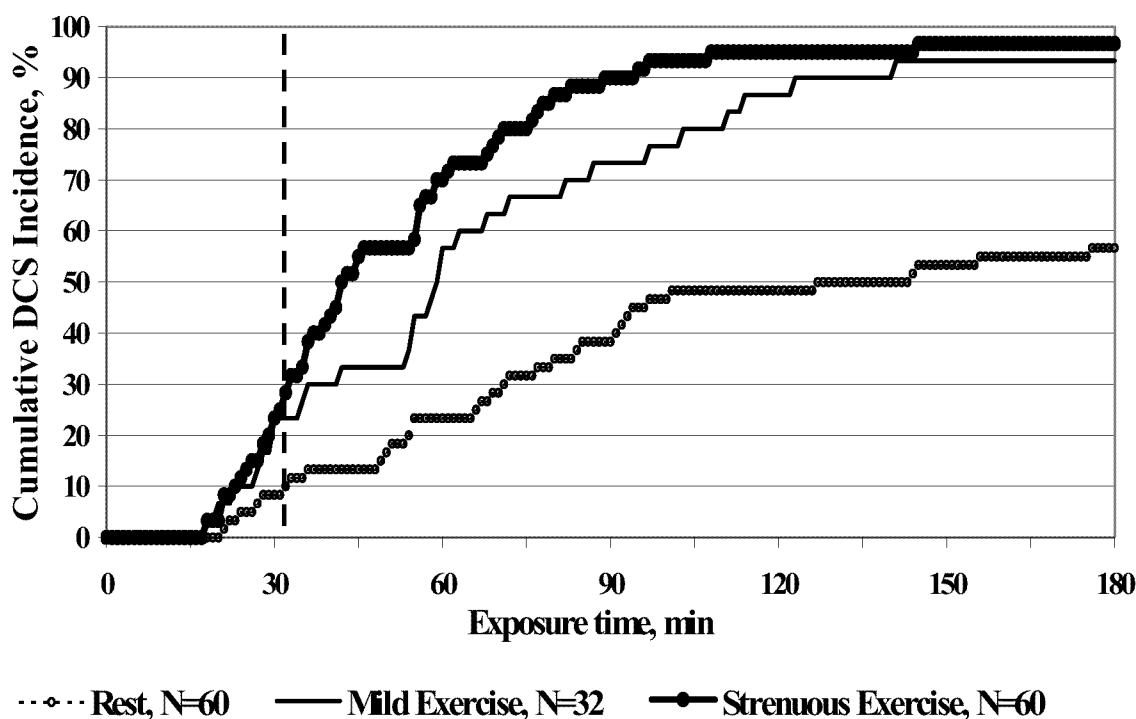


Figure 6. Cumulative DCS vs. exposure time to 35,000 ft

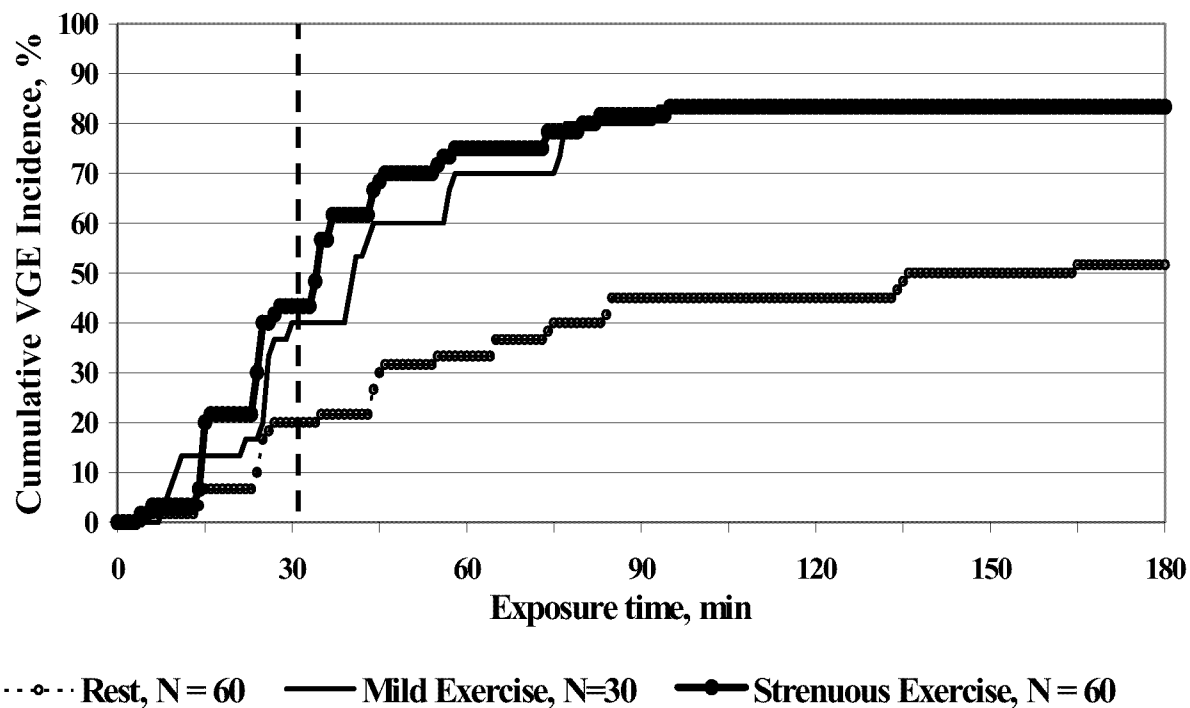


Figure 7. Cumulative VGE vs. exposure time to 35,000 ft

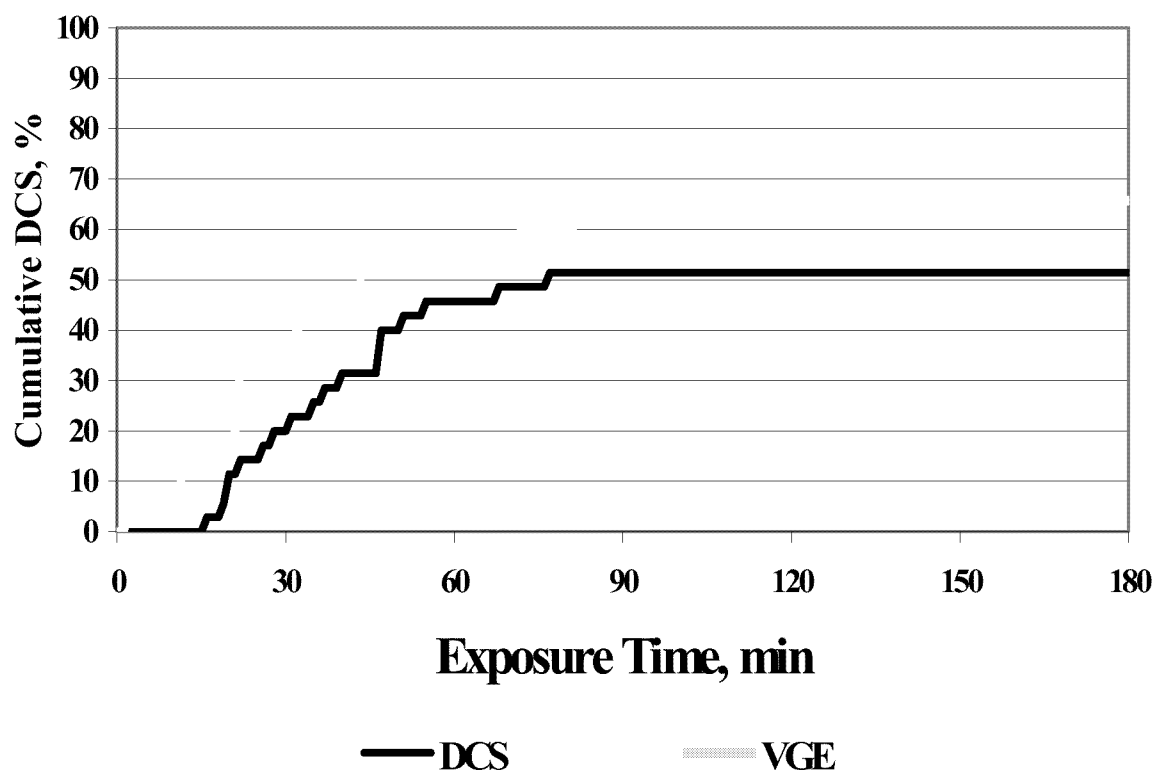


Figure 8. Cumulative DCS vs. exposure time to 40,000 ft

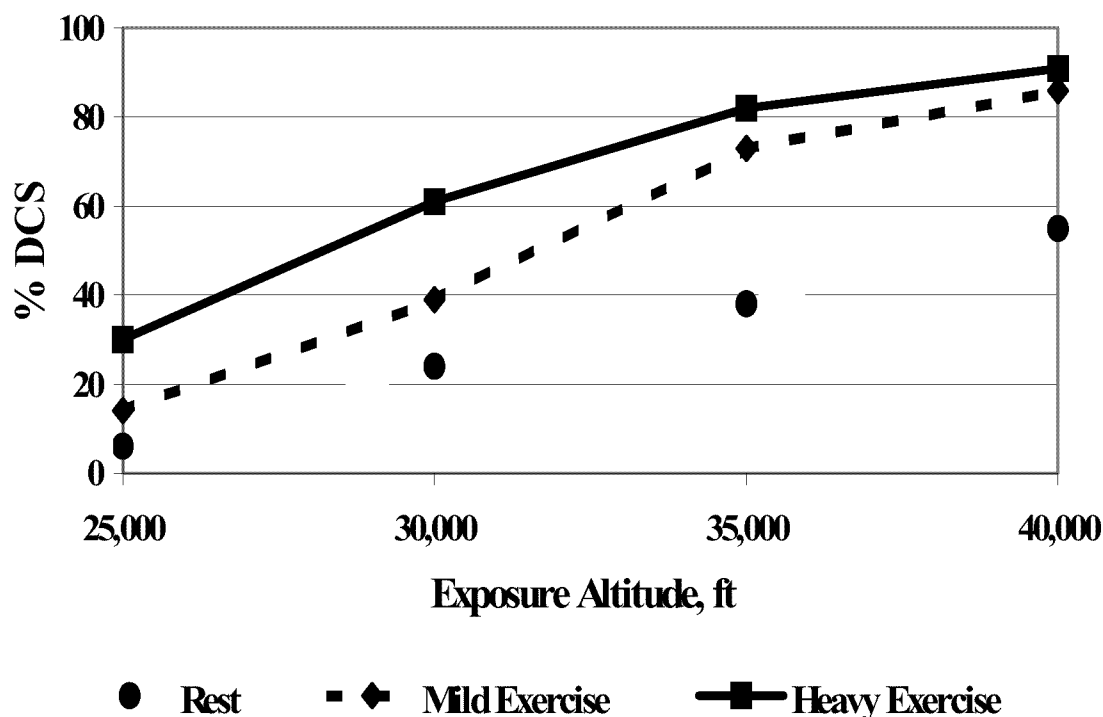


Figure 9. DCS vs. exposure altitude for rest, mild and strenuous exercise at altitude.

With 75 min of preoxygenation, a 3-h resting exposure to 35,000 ft produces a relatively high incidence of DCS (57%). Performance of mild exercise results in 94% DCS (Fig. 6) and strenuous exercise results in 97% DCS. No difference was observed in the shape of the incidence versus exposure time curves between mild and strenuous exercise.

Although the onset of DCS is more rapid at 35,000 ft than at lower altitudes with similar preoxygenation, the incidence of severe DCS symptoms was very low during these studies. The results of exposures to 35,000 ft during WWII, during which severe symptoms were commonplace, were probably influenced by both shorter (or nonexistent) preoxygenation and termination criteria which allowed more severe symptom development prior to recompression (11, 17, 19). Severity of symptoms during the current studies was kept low due to rapid recompression at symptom onset which probably reduced progressive symptom development.

These findings reinforce the current Air Force policy regarding exposure to 35,000 ft. The current 30-min limit on exposures to 35,000 ft following 75 min of preoxygenation has been shown to keep symptoms relatively low, especially if no exercise is performed (10%). This information emphasizes the need to avoid exercise while decompressed. The consequence of exceeding 30 min of exposure, especially if exercising, is a rapid increase in DCS incidence.

Figure 8 shows preliminary data for 3 hour resting exposures to 40,000 ft with 90 min of preoxygenation. The DCS onset curve is slightly steeper than at 35,000 ft., otherwise, the results appear to be similar to those at 35,000 ft. Finally, in Figure 9 the relationship between DCS incidence and increasing altitude appears to be almost linear. At the higher altitudes there is no difference between mild and strenuous exercise, while at lower altitudes the difference is apparent. The numbers for this figure were generated by the ADRAC model which is based on validated human trials (ADRAC was described in an earlier paper at this meeting).

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