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The Effect of Exercise on Venous Gas Emboli and Decompression Sickness in Human Subjects at 4.3 psia

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ABSTRACT

The contribution of upper body exercise to altitude decompression sickness, at a pressure of 4.3 psia after 3.5 or 4.0 hours of 100 percent oxygen prebreathing at a pressure of 14.7 psia, was determined by comparing the incidence and the patterns of venous gas emboli (VGE) and the incidence of Type I decompression sickness (DCS) in 43 exercising male subjects and 9 less active male Doppler Technicians (DT's). The effect of exercise that simulates Space Shuttle extravehicular activities (EVA's) on altitude decompression sickness is an important consideration in the development of effective DCS preventive procedures.

One DT accompanied three subjects to 4.3 psia for either a 4.0-hour exposure after a 3.5-hour oxygen prebreathe or for a 6.0-hour exposure after a 4.0-hour oxygen prebreathe. The DT provided proper positioning of an ultrasonic bubble-detecting transducer on the chest over the pulmonary artery. Only the subjects performed rhythmic upper body exercises that included torquing fixed studs, and cranking and pulling from devices that provided constant resistance.

Each subject exercised for 4 minutes at each of the three exercise stations. An additional 4 minutes were spent monitoring for VGE while the subject was supine on an examination cot. The subject's arms and legs were sequentially flexed three times to improve bubble detection, and every hour, the subjects and the DT's were questioned as to condition. Immediate reports of pain, discomfort, or any other symptoms by the subjects and the DT's were encouraged by the ground-based medical support team.

On the basis of ground-based laboratory metabolic measurements, DT's averaged 126 ± 15 kcal/hr and exercising subjects averaged 166 ± 17 kcal/hr. Peak metabolic rates were obtained while using the torque station (189 ± 29 kcal/hr). In the combined 3.5- and 4.0-hour oxygen prebreathe data, 13 (25 percent) subjects complained of Type I DCS compared to 9 (31 percent) complaints from DT's. Venous gas emboli were detected in 28 (55 percent) subjects compared to 14 (48 percent) VGE detections from DT's. A chi-square analysis of proportions revealed no statistically significant difference in the incidence of Type I DCS or VGE between exercising subjects and less active DT's.

Although the incidence of DCS and VGE in the two groups did not differ, the average time required to detect VGE and to report Type I DCS symptoms was statistically different based on the Wilcoxon rank sum test. In the combined data, DT's complained of DCS symptoms 195 ± 55 minutes into the exposure compared to 140 ± 80 minutes for the exercising subjects. Venous gas emboli were detected at 156 ± 69 minutes in the DT's compared to 98 ± 56 minutes for the subjects.

Lower body exercise was avoided in these tests; however, all 22 reports of Type I DCS symptoms occurred in the knees, the ankles, or the feet of DT's and subjects. Venous gas emboli were detected in the venous return from the upper body in only 3 of 42 instances. Intrasubject, intersubject,

and DT variability to DCS and VGE was evident. Even with no exercise, DT's were not immune to DCS or VGE, and 46 percent of the exercising population never contracted symptoms or developed VGE.

It is concluded that exercise at metabolic rates simulating EVA metabolic rates hastens the initial detection of VGE as well as the time of reporting Type I DCS symptoms as compared to the absence of exercise.

INTRODUCTION

The purpose of this report is to compare the incidence and the patterns of VGE and the incidence of Type I DCS induced by exposure to a pressure of 4.3 psia (equivalent altitude of 9144 meters) among two test groups. Each group performed identical denitrogenation procedures prior to identical altitude exposures. The test subjects performed moderate upper body exercises and the DT's monitored the test subjects electronically for the presence of VGE but performed no exercise. It is possible to assess the function of exercise on the expression of altitude decompression sickness under these conditions.

An increase in the incidence of Type I DCS during exercise after altitude decompression has been extensively documented (refs. 1 to 3). Type I DCS is defined as simple limb bends and/or cutaneous and lymphatic manifestations (ref. 4). The mechanism, or the combination of mechanisms, responsible for the increased incidence as a result of various types and intensities of exercise has not been clearly determined (refs. 3, 5, and 6). Differences are apparent in the incidence of DCS depending on whether isotonic or isometric exercise is employed (ref. 7). The function of carbon dioxide in the final expression of Type I symptoms is still unclear.

Space Shuttle Orbiter crewmembers require protection from DCS during EVA under the current Space Shuttle EVA suit design. Crewmembers must make the transition from the 14.7-psia pressure of the Orbiter cabin, which contains 78 percent nitrogen, to the suit environment of 100 percent oxygen at 4.3 psia. Decompression requires a procedure to denitrogenate the astronauts before EVA to prevent DCS. Exercise during EVA may significantly alter the effectiveness of the denitrogenation procedure to prevent DCS.

Two primary reasons for EVA are to perform useful work and to make emergency repairs. Important factors to consider in any DCS protection procedure are the type, the intensity, and the duration of the work that will occur during single or multiple EVA's. The work performed by aviators in high-altitude aircraft (ref. 8) differs from that performed during EVA's in type, intensity, and duration; thus, data on the incidence of DCS in the aviation environment may not be directly applicable to EVA crewmembers. A pattern of moderate levels of upper body exertion, with brief periods of peak activity, has been typical of past EVA's (ref. 9).

Oxygen prebreathing has been used routinely to prevent DCS in aviators and was reevaluated under conditions specific to the Space Shuttle. Tests have been conducted to evaluate two denitrogenation procedures followed by simulated EVA work profiles while at 4.3 psia. Oxygen prebreathing of the DT's was identical to that performed by the subjects, but the DT's did not exercise upon reaching 4.3 psia.

METHODS

All participants met the requirements of a U.S. Air Force (USAF) Class III flight physical examination, and each underwent an additional medical examination immediately before each test. Table 1 is a comparison of the physical characteristics of each group. The data indicate no statistically significant difference (Student's unpaired t-test) between the two groups; they are homogeneous for the physical characteristics shown.

Both DT's and test subjects performed 3.5 or 4.0 hours of uninterrupted 100 percent oxygen prebreathing at site pressure (14.7 psia) before decompression to 4.3 psia for 4.0 or 6.0 hours of exposure. All participants used oxygen demand breathing systems and were in constant communication with chamber and medical support teams.

One DT accompanied three subjects to 4.3 psia. He positioned a 5-kHz ultrasonic Doppler transducer in the vicinity of the pulmonary artery during periods of VGE monitoring.[1] Each DT had the opportunity to monitor himself throughout the altitude exposure. The three subjects and one DT were questioned as to condition every hour, and they were encouraged to report any untoward symptoms. Only the DT and medical support personnel were aware of VGE activity detected by the Doppler device.

After performing three 4-minute sequential exercise routines at 4.3 psia, the subject assumed a supine position and was monitored for 4 minutes with the Doppler Bubble Detector while rhythmically flexing each limb three times with wrist and ankles being actively rotated (ref. 10). Audio feedback signals generated by VGE passing beneath the transducer were used to grade bubbles on Spencer's zero-to-four scale (ref. 11). A zero grade represents the absence of bubbles in the cardiac cycle; grade 1 is assigned when an occasional bubble is detected in several cardiac cycles. Grade 2 indicates bubbles in less than half of several cardiac cycles and grade 3 represents bubble signals in all cardiac cycles, but not to the point of obscuring signals of cardiac motion. Grade 4 classification represents a condition wherein bubbles are detected in all of the cardiac cycles to the point of obscuring signals of cardiac motion.

The altitude chamber was configured in the geometry of the Space Shuttle's upper flight deck and middeck including the airlock. Decompression in the chamber was gradual and staged to simulate operational conditions in the Space Shuttle. Pressure was reduced from 14.7 psia to 9.3 psia

[1]Model 1032G Doppler Bubble Detector, Institute of Applied Physiology and Medicine, Seattle, Washington.

at 0.96 psi/min. Ten minutes elapsed at 9.3 psia before continuing decompression to 5.2 psia at the same rate. Exercise then began and chamber pressure was decreased to 4.3 psia in 10 minutes at 0.1 psi/min. Total decompression from site pressure to 4.3 psia required 29.5 minutes; recompression rates were constant at 1.73 psi/min.

Three exercise stations were developed after a review of activities performed during previous EVA's. The Pull Station was a Mini-Gym apparatus which was set to 16.7 kg of resistance.[2] It offered constant resistance to arm flexion and, therefore, provided for isotonic contractions. Subjects were seated at this exercise station with the handle positioned 116 centimeters from the floor. The "A" cycle consisted of pulling once every 5 seconds with the right arm and once every 5 seconds with the left arm for a period of 4 minutes. The "B" cycle involved placing both hands on the handle while pulling twice in a 5-second period for 4 minutes.

The Crank Station was a modified ergometer which was set to 6 newtons of resistance.[3] A subject stood at this exercise station with the handle positioned 104 centimeters from the floor. The "A" cycle consisted of cranking three times in 5 seconds with the right hand rotating clockwise. A 5-second rest was taken, then the three cranks were repeated. The "B" cycle, also a 4-minute exercise, was performed at the "A"-cycle rate except using the left hand and cranking counterclockwise.

The Torque Station consisted of ten 3/8-inch fixed studs. Five studs were positioned in the lower left corner of a mounting plate, whereas the remaining five studs were positioned in the upper right corner of the same plate. Subjects stood at this exercise station with the lower studs 107 centimeters above the floor.

The torquing pattern consisted of holding a torque wrench at 400 cm-kg for 5 seconds during one "push" and one "pull" cycle. A total of 24 separate torques were performed in a 2- to 3-minute period. The remaining time was spent stressing the wrist with a ball ratchet device by placing it sequentially on several studs. The subject maintained the torque for 5 seconds. The right hand was used in the "A" cycle, and the left hand was used in the "B" cycle.

The Torque Station provided isometric muscle contractions in the upper body. The feet were comfortably positioned at this workstation and exercise of the lower body was minimal. Other than walking to the exercise stations and flexing the knee during VGE monitoring, the knees and the ankles were not exercised. Exercise at altitude began with each subject positioned at an exercise station. After each subject performed exercise cycle "A" for 4 minutes, he would move to the next station. After performing three 4-minute exercises, the subject was monitored for VGE. He then performed three

[2]Model 180X Isokinetic Exerciser. Mini-Gym, Inc., Independence, Missouri.

[3]Model 194EM Monark Ergometer Cycle, MacLevy Products Corp., Elmhurst, New York.

4-minute "B"-cycle exercises, was monitored for VGE, and was allowed to rest for a 4-minute period. The DT had the opportunity to monitor himself after every 16-minute cycle.

Total exposure time at 4.3 psia after the 3.5-hour oxygen prebreathe was 4.0 hours; after the 4.0-hour oxygen prebreathe, 6.0 hours. An additional 16 minutes of rest after 3.0 hours of exercise was given to the subjects and the DT because of the 6.0-hour altitude exposure. One complete work cycle, including the rest period at the end of the "B" cycle, required 36 minutes. Drinking water was available during the 6.0-hour altitude exposures.

Each subject performed a practice exercise protocol for 3.0 hours several days before his altitude exposure (1) to train each subject on the exercise patterns and (2) to collect subjective data on how each exercise station affected the subject. Muscle strains, arm or hand weakness, and minor joint pains were recorded. Later, this information was used to more accurately diagnose Type I DCS when a subject reported symptoms while exercising at 4.3 psia.

Metabolic rates, based on measured oxygen consumption (ref. 12), were collected on a representative sample of the 43 subjects and the 9 DT's who participated in these studies. Ten subjects and three DT's were tested to quantify the energy expenditure during exercise and rest for the 3-hour ground-based test. The resulting metabolic rates were extrapolated to the exercise and resting conditions while at 4.3 psia.

Three statistical methods were employed to analyze the ground-based and altitude exposure data. All three methods require independence within the compared samples. Nine DT's were exposed a total of 29 times to 4.3 psia; 43 subjects were exposed a total of 51 times. Repeat exposures were more common for the DT's than for the subjects. The data compiled on physical characteristics and on DCS and VGE parameters were averaged to provide a single value when multiple exposure was available for DT's or subjects.

An unpaired Student's t-test was used to test differences in physical characteristics between the two groups. A chi-square analysis of proportions was used to compare DCS and VGE incidence between the two groups and any differences between the 3.5- and 4.0-hour oxygen prebreathes. The Wilcoxon rank sum test compared the data on VGE and DCS parameters and the effect of 3.5 and 4.0 hours of oxygen prebreathe on those parameters. Differences in means were considered statistically significant at $p < 0.05$ level.

RESULTS

Figure 1 contains the results of the measured ground-based metabolic rates on 10 subjects and 3 DT's as they performed at the exercise stations. The Torque Station produced the greatest energy expenditure (189 ± 29 kcal/hr). In this exercise, the elbow, shoulder, and wrist joints developed internal isometric tension but were not articulated. This exercise contrasts with the isotonic muscle contraction induced using the Pull and Crank Stations. Using these devices, energy expenditure was less and the joints did articulate during exercise. Both types of exercise are expected during EVA's.

The nonexercising DT's averaged 126 ± 15 kcal/hr, which was lower than the average metabolic rate of 166 ± 17 kcal/hr for the combined exercise and rest conditions in exercising subjects. For comparison, sitting at rest requires 120 kcal/hr (ref. 13), whereas the average metabolic rate in early Space Shuttle EVA's was 196 kcal/hr (ref. 9). The exercise profile adequately simulated the exercise type and intensity produced during past EVA's.

Table 2 shows that 23 subject decompressions to 4.3 psia after the 3.5-hour oxygen prebreathe at 14.7 psia resulted in 7 (30 percent) reports of Type I DCS with 15 (65 percent) subjects having detectable VGE. Under the same prebreathing conditions, 12 DT exposures to 4.3 psia for 4.0 hours resulted in 2 (17 percent) cases of Type I DCS with 5 (42 percent) DT's having detectable VGE.

Following the 4.0-hour oxygen prebreathe, 28 subject exposures after 6.0 hours at 4.3 psia produced 6 (28 percent) reports of Type I DCS with 13 (46 percent) subjects having detectable VGE. Seventeen DT exposures produced seven (41 percent) cases of Type I DCS with nine (53 percent) DT's having detectable VGE after performing the identical 4.0-hour oxygen prebreathe.

A chi-square analysis of proportion (ref. 14) showed there were no statistically significant differences in the incidence of Type I DCS or VGE between exercising subjects and sedentary DT's when the results from the 3.5- and 4.0-hour oxygen prebreathe procedures were analyzed. When the data from both procedures were combined for both groups, the DT's and the subjects still had a similar incidence of VGE and Type I DCS. The level and/or type of exercise did not separate the DCS and VGE incidence between the DT's and the subjects.

Subjects and DT's experienced similar patterns of bubble dynamics (grade of initial bubbles detected, time to reach maximum bubble grade, average maximum bubble grade, duration of maximum bubble grade, and time to decrease to lowest bubble grade) while at 4.3 psia. Although the basic bubble dynamics were similar, DT's developed VGE approximately one hour later than exercising subjects. Table 3 shows that the average time to the initial appearance of VGE in DT's using the 4.0-hour oxygen prebreathe procedure was 166 ± 74 minutes (154 minutes median) after reaching 4.3 psia, whereas detection of bubbles in subjects occurred 73 ± 43 minutes (65 minutes median) after exercise began. The difference was significant at $p < 0.025$ level using the Wilcoxon rank sum test (ref. 14). This nonparametric test compares the median of the ranked data to determine a significant difference in two samples; therefore, the median is presented with sample mean.

An analysis of the 3.5-hour oxygen prebreathe procedure indicated a similar trend in the onset of VGE but the variation was not statistically different. The times recorded were 144 ± 80 minutes (117 minutes median) for DT's and 122 ± 58 minutes (116 minutes median) for subjects. Table 3 contains additional data on significant events related to VGE activity.

Before the data in table 3 were combined to analyze an exercise effect with a larger sample, the contribution of an additional 30 minutes of oxygen prebreathing was determined. To determine the effect of 30 minutes of additional oxygen during the prebreathe, the Wilcoxon rank sum test was used to compare DCS and VGE parameters (table 3) of subjects who performed 3.5- and 4.0-hour oxygen prebreathing. The same parameters for the DT's were compared. The statistical evaluation indicated that exercising subjects, after the 3.5-hour oxygen prebreathe, provided DCS and VGE data that were not statistically different from the data of the subjects after 4.0 hours of oxygen prebreathing, and the analysis of the DT data provided the same results.

An analysis was then done on the combined 3.5- and 4.0-hour data. In the combined data, DT's developed VGE 156 ± 69 minutes (136 minutes median) into the exposure, whereas bubble activity of the subjects began at 98 ± 56 minutes (105 minutes median). This difference was significant at $p < 0.05$ level using the Wilcoxon rank sum test.

The average time to reach maximum bubble grade also occurred later in the DT's. However, the time from initial VGE detection to maximum detected bubble activity for the DT's and the subjects was approximately the same (25 minutes) regardless of the prebreathe procedure or the exercise level. The absolute time for which the bubble grade remained high was also the same (100 minutes) for each group in the combined data. The average time required for bubble grade to decay from the highest to the lowest grade in the 4.0-hour protocol in those tests in which bubble grade decreased before the end of the test were also similar for the DT's and the subjects (90 minutes).

The effect of exercise on the time course and the bubble grade of VGE is shown in figures 2 and 3. Figure 2 illustrates combined data on the average venous bubble grade from exposure of 14 DT's and 28 subjects, where bubble activity after the oxygen prebreathe procedures was recorded. The average initial bubble grade and peak bubble grade for DT's and subjects were similar; however, the time of initial VGE activity occurred earlier in the exercising subjects. The average time to report Type I symptoms also was plotted and, in both cases, occurred before detection of the highest average bubble grade when the individual flexed his limbs. Figure 3 displays the same data except that the initial time of bubble appearance was set to zero in each group. A comparison of the data reveals that the actual time course and bubble grade of VGE were similar regardless of exercise.

Figures 2 and 3 exhibit VGE grade; however, nothing can be reported about the volume of gas traveling to the lungs of DT's or subjects with the instrumentation used because the bubble detecting system could only detect the presence of a gas phase and not the cumulative volume that passed beneath the sensor. A bubble grade of 4 was assigned under all conditions in which bubble sounds were heard in all cardiac cycles regardless of the length of the bubble shower; therefore, DT's could receive a bubble grade of 4 even though the grade 4 condition existed for short times, whereas the same grade 4 could be assigned to a subject who experienced a continual shower of bubbles.

No statistically significant difference was seen in the average time required to report Type I symptoms for the seven DT exposures (144 ± 88 minutes with 180 minutes median) versus the time for the six subject exposures (141 ± 114 minutes with 97 minutes median) after the 4.0-hour protocol. Seven subjects in the 3.5-hour protocol developed symptoms after 139 ± 43 minutes (148 minutes median) of exercise, whereas one DT developed a symptom in his knee at 205 minutes. When the data from the 3.5- and 4.0-hour procedures were combined, subjects reported Type I symptoms at 140 ± 80 minutes (124 minutes median) as compared to 195 ± 58 minutes (205 minutes median) for the DT's (Fig. 2). This difference was significant at $p < 0.05$ level using the Wilcoxon rank sum test. The difference in the average time required to report Type I symptoms between subjects and DT's in the combined data was 55 minutes, which corresponds to the difference in the average time of the first detection of VGE between the groups (58 minutes).

The location of Type I DCS symptoms was exclusively in the knee and ankle joints, although the lower body was not actively exercised. The symptoms were often apparent when the legs were extended horizontally during limb flexing while the subjects were supine on the examination cot. The most common symptom reported was a joint awareness that sometimes graduated to a dull ache around the joint; most often, it was perceived as being under the patella. No symptom occurred in the upper body. In only three instances VGE were determined to have originated in the upper body.

DISCUSSION

Results of earlier studies (refs. 1, 3, 7, and 15) have indicated that higher levels of exercise substantially contribute to Type I DCS. The type and the intensity of exercise used during these tests did not result in a difference in the incidence of DCS and VGE between less active DT's and exercising subjects. An exercise effect was seen as a decrease in the time of initial VGE appearance within the pulmonary artery and the time of the first report of Type I DCS symptoms in the exercising subjects compared to the nonexercising DT's.

The exercise stations were designed to provide realistic upper body exercise; yet, no DCS symptoms occurred in the upper body. The USAF field reports also indicate a low incidence of upper body DCS symptoms (ref. 8). A study of DCS in the USAF from 1970-80 revealed that 22 of 69 (32 percent) occurrences of Type I DCS were located in the knees of aviators. An additional 29 percent of reported Type I DCS symptoms were located in the shoulders, with the remaining 39 percent occurring in the elbows, the ankles, the leg muscles, the wrists, the hip, and the neck (ref. 8). Even though Space Shuttle crewmembers may perform primarily upper body exercise during EVA's, the data suggest that joints in the lower body may be the most likely areas to develop Type I symptoms.

The fact that VGE and Type I DCS occurred earlier (Fig. 2) in exercising subjects compared to less active DT's after identical oxygen prebreathing suggests that a finite amount of nitrogen is available to be released from tissues, or to be sequestered in a joint, and that muscle contraction, especially in the lower body, hastens the release of trapped gas into the venous return. The contribution of carbon dioxide in the earlier presence of VGE in exercising subjects remains unclear; bubbles evolved early, late, or not at all in both subjects and DT's. Only when the average times for bubble parameters are calculated does one find a consistent trend toward earlier VGE presence and reports of Type I DCS in exercising subjects. The data reveal extreme intraindividual and interindividual variability in VGE production and DCS symptoms. In general, however, bubbles evolved slowly, rose to a peak, then decayed to a lower grade in both DT's and subjects even though the subject's exercise was continual and rhythmic throughout the tests.

Figure 3 shows that exercise did not influence the initial bubble grade detected, the time to reach maximum bubble grade, or the time to decrease from a maximum grade to a lesser bubble grade once the time difference in initial VGE detection had been removed. This evidence suggests that exercise at this level hastens the initial release of VGE. However, once the process of gas release from a limb has begun, the rate of increase, the duration, and the eventual resolution of the VGE, as detected and graded using the Doppler instrument, is similar to the pattern exhibited under nonexercising conditions.

In summary, exercise that simulated EVA activities had an effect on altitude decompression sickness in subjects relative to nonexercising DT's. Less active DT's were not immune to Type I DCS, while 46 percent of the exercising population never exhibited symptoms or developed VGE.

On the basis of a literature survey (refs. 1 to 3, 7, and 15) and the observed trends in this study, greater workloads than those tested, and exercises that involve the knees and ankles, may be expected to have a greater effect on the development of DCS.

CONCLUSIONS

The following conclusions can be drawn.

1. There was no difference in the incidence of Type I DCS and VGE between exercising subjects and less active DT's.

2. The exercise profile did have an effect on the average time of initial appearance of VGE and the reporting of Type I DCS. Exercising subjects evolved VGE and complained of Type I DCS symptoms earlier than did DT's.

3. All reports of Type I DCS and all but three VGE detections originated in the lower body. The knee is particularly susceptible to DCS symptoms in these protocols even when lower body exercise is avoided.

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TABLE 1.- SUBJECT AND DOPPLER TECHNICIAN PHYSICAL CHARACTERISTICS

Test subject type, number	Total number of exposures	X age, yr	X weight, kg	X height, cm	X body fat, %
Doppler Technicians, N = 9	29	31 ± 9[a]	72 ± 8	175 ± 7	13 ± 4
Subjects, N = 43	51	31 ± 7	77 ± 7	176 ± 5	12 ± 3

[a]Standard deviation.

TABLE 2.- INCIDENCE OF VGE AND DCS IN EXERCISING SUBJECTS AND DOPPLER TECHNICIANS

Test subject type	Number of altitude exposures	VGE detected	DCS reported
	3.5-hour prebreathe		
Subjects	23	15 (65%)	7 (30%)
Doppler Technicians	12	5 (42%)	2 (17%)
	4.0-hour prebreathe		
Subjects	28	13 (46%)	6 (28%)
Doppler Technicians	17	9 (53%)	7 (41%)
	Combined results		
Subjects	51	28 (55%)	13 (25%)
Doppler Technicians	29	14 (48%)	9 (31%)

TABLE 3.- EFFECT OF MILD EXERCISE ON VARIOUS DCS PARAMETERS

Test subject type	Time, min, ± standard deviation			
	First bubble detection	Maximum bubble grade	Bubble grade decreased	First symptom report
	3.5-hour prebreathe			
Subjects	122 ± 58	146 ± 57	213 ± 31	139 ± 43
Doppler Technicians	144 ± 80	155 ± 77	217 ± 32	205 ± 0
	4.0-hour prebreathe			
Subjects	73 ± 43	103 ± 55	221 ± 52	141 ± 114
Doppler Technicians	166 ± 74	191 ± 71	295 ± 61	144 ± 88
	Combined results			
Subjects	98 ± 56	125 ± 59	217 ± 41	140 ± 80
Doppler Technicians	156 ± 69	176 ± 70	295 ± 61	195 ± 55

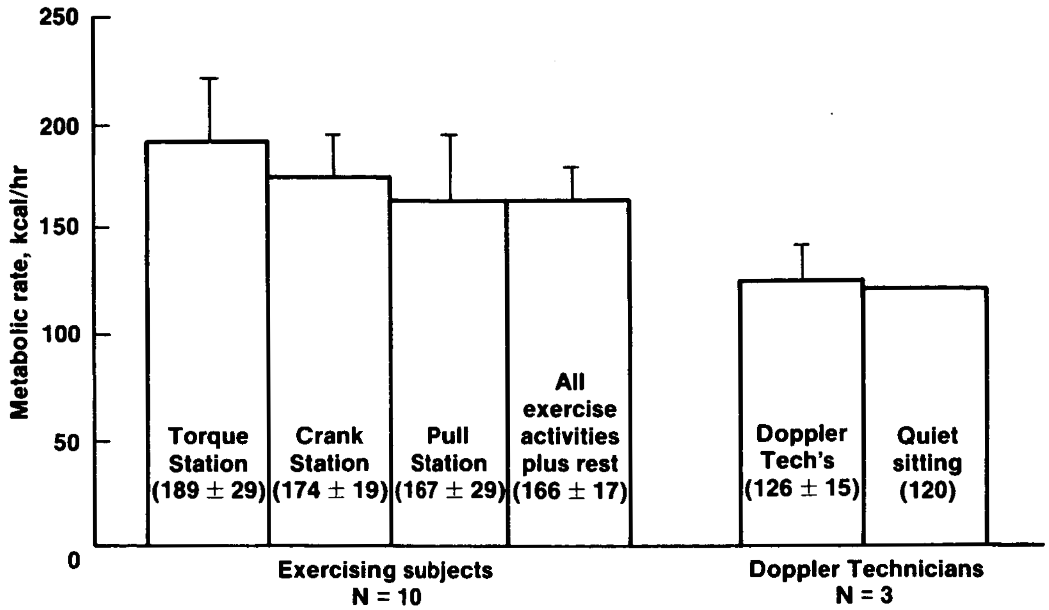

Figure 1.- Metabolic rate during exercise on three test apparatuses with comparison to Doppler Technician metabolic rate.

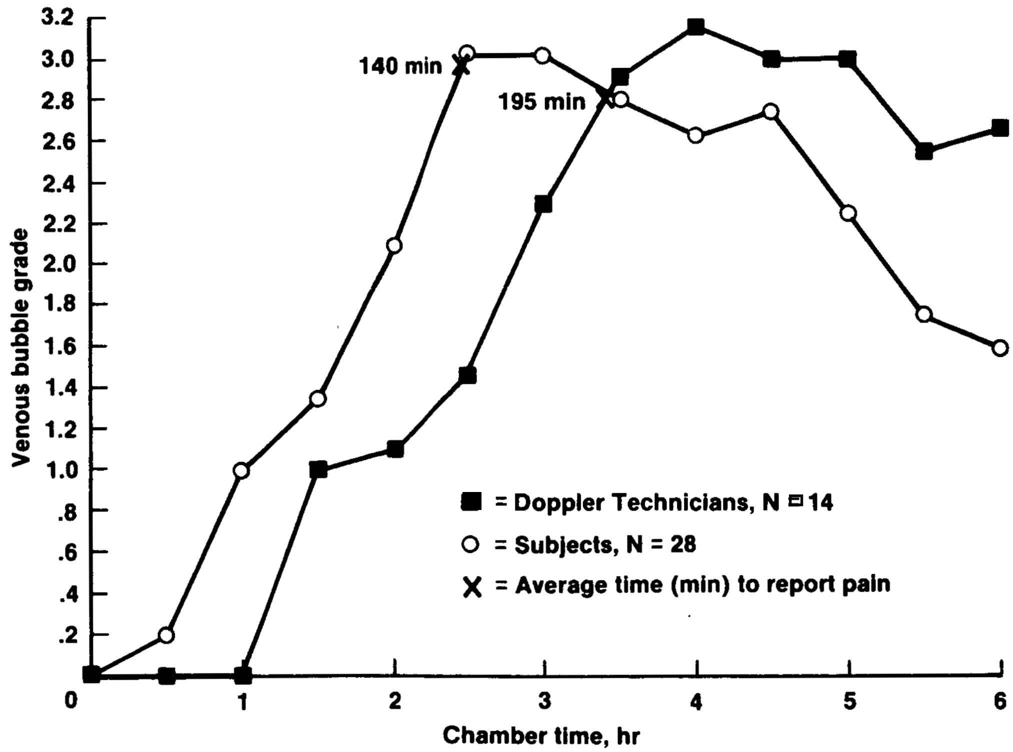

Figure 2.- Comparison of average VGE grade during exposure to 4.3 psia in exercising subjects and less active Doppler Technicians. Note the average time to report Type I DCS symptoms for each group.

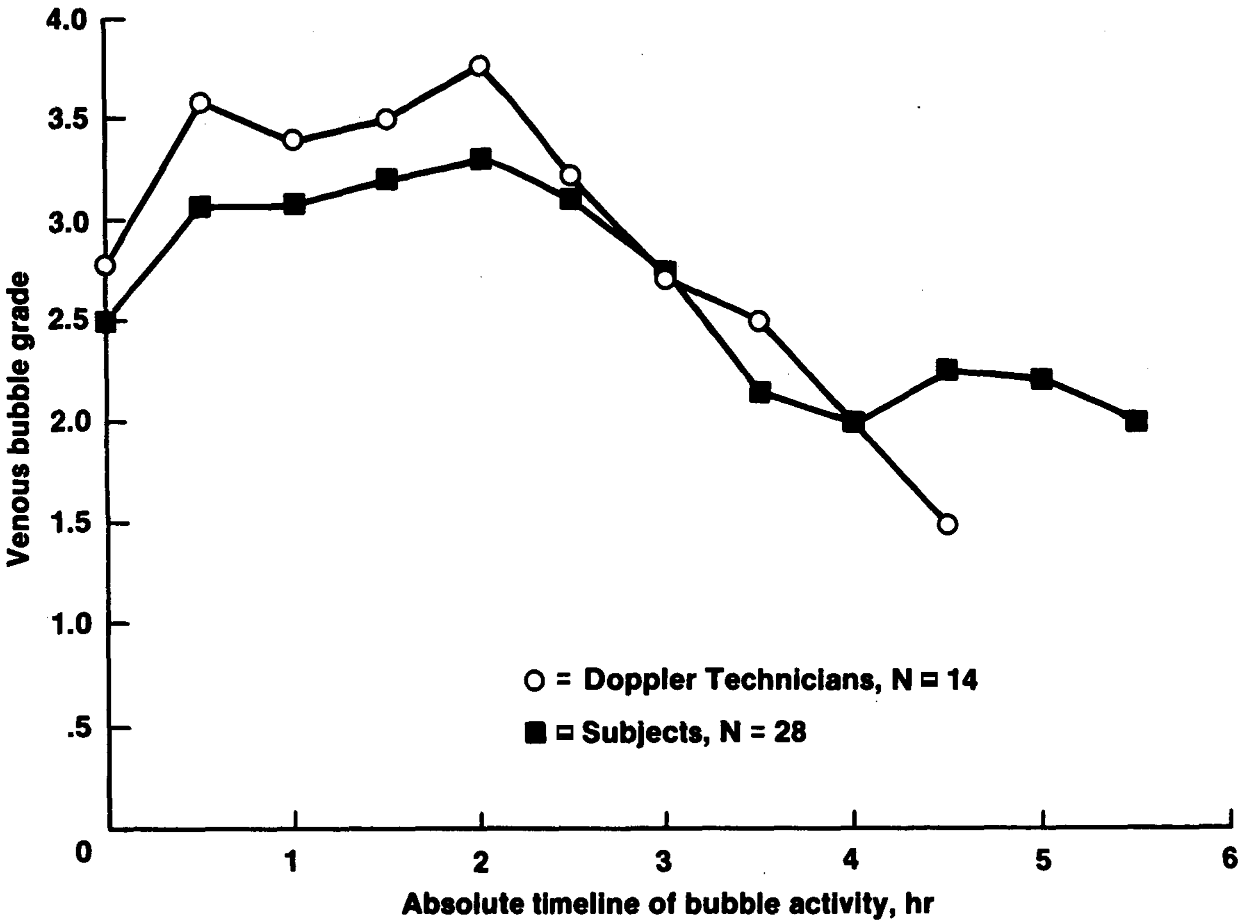

Figure 3.- Comparison of VGE patterns in exercising subjects and less active Doppler Technicians exposed to 4.3 psia. The time of first bubble detection is set to zero in each group to eliminate differences in initial bubble detection time.

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15. Supplementary Notes

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16. Abstract

The contribution of upper body exercise to altitude decompression sickness while at 4.3 psia after 3.5 or 4.0 hours of 100% oxygen prebreathing at 14.7 psia was determined by comparing the incidence and patterns of venous gas emboli (VGE), and the incidence of Type I decompression sickness (DCS) in 43 exercising male subjects and 9 less active male Doppler Technicians (DT's). Each subject exercised for 4 minutes at each of 3 exercise stations while at 4.3 psia. An additional 4 minutes were spent monitoring for VGE by the DT while the subject was supine on an examination cot.

In the combined 3.5- and 4.0-hour oxygen prebreathe data, 13 (25%) subjects complained of Type I DCS compared to 9 (31%) complaints from DT's. VGE were detected in 28 (55%) subjects compared to 14 (48%) detections from DT's. A chi-square analysis of proportions showed no statistically significant difference in the incidence of Type I DCS or VGE between the two groups; however, the average time to detect VGE and to report Type I DCS symptoms were statistically different (Wilcoxon rank sum test). DT's complained of DCS symptoms 195 ± 55 minutes into the exposure compared to 140 ± 80 minutes for the exercising subjects. VGE were detected at 156 ± 69 minutes in the DT's compared to 98 ± 56 minutes for the subjects.

It is concluded that 4 to 6 hours of upper body exercise at metabolic rates simulating EVA metabolic rates hastens the initial detection of VGE and the time to report Type I DCS symptoms as compared to DT's who performed no exercise.

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