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MIPR NUMBER: 95MM5575

TITLE: The Effect of Gender on Susceptibility to Altitude Decompression Sickness

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REPORT DATE: February 1996

TYPE OF REPORT: Final

PREPARED FOR: U.S. Army Medical Research and Materiel Command  
Fort Detrick, Maryland 21702-5012

DISTRIBUTION STATEMENT: Approved for public release; distribution unlimited

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DTIC QUALITY INSPECTED 3

19970821 015

# REPORT DOCUMENTATION PAGE

Form Approved  
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE February 1996	3. REPORT TYPE AND DATES COVERED Final (9 Jan 95 - 30 Sep 95)
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4. TITLE AND SUBTITLE  The Effect of Gender on Susceptibility to Altitude Decompression Sickness	5. FUNDING NUMBERS  95MM5575
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6. AUTHOR(S)  Andrew A. Pilmanis, Ph.D., James T. Webb, Ph.D.	
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  Armstrong Laboratory/CFTS Brooks Air Force Base, Texas 78235-5104	8. PERFORMING ORGANIZATION REPORT NUMBER
--	--

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  U.S. Army Medical Research and Material Command Fort Detrick, MD 21702-5012	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
---	--

11. SUPPLEMENTARY NOTES  
  
This research was conducted, in part, under USAF Contract #F33615-92-C-0018; JOCAS 718458A2

12a. DISTRIBUTION/AVAILABILITY STATEMENT  Approved for public release; distribution unlimited	12b. DISTRIBUTION CODE
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13. ABSTRACT (*Maximum 200 words*)

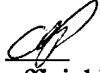
Inclusion of females in combat roles places some of them in cockpits where decompression sickness (DCS) in their male counterparts occurs on a routine basis. A retrospective review of data from 765,216 training chamber exposures indicated females are 4.6 times more susceptible to DCS than males (0.224% in females versus 0.049% in males). Relevant published data from research chamber human subject protocols are scarce and equivocal. A research chamber study comparing female and male susceptibility to DCS was initiated at the Armstrong Laboratory at Brooks AFB, TX. The six-h, zero-preoxygenation exposures used a breathing gas of 100% oxygen during exposure and subjects performed mild exercises while decompressed. Altitude of exposure in ft, number of subjects and gender (M or F), and % DCS incidence were, respectively: 15,000, 10M, 0%; 16,500, 8M, 0%; 18,100, 10M, 0%, 10F, 0%; 19,800, 10M, 0%, 10F, 10%; 21,200, 17M, 6%; 22,500, 18M, 50%, 2F, 0%; 23,800, 10M, 50%. No statistical comparison could be made of DCS susceptibility due to the low number of female subjects exposed at the altitudes where DCS was common in male subjects. Further research is needed at higher altitudes under identical conditions with both genders to enable comparisons of DCS susceptibility.


14. SUBJECT TERMS Decompression sickness, gender, venous gas emboli, susceptibility Defense Women's Health	15. NUMBER OF PAGES 19
	16. PRICE CODE

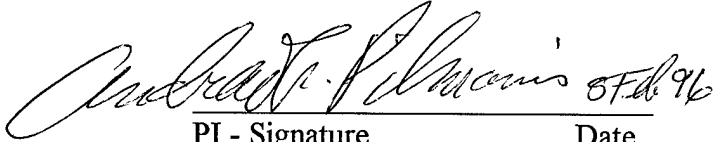
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT Unlimited
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## FOREWORD

Opinions, interpretations, conclusions and recommendations are those of the author and are not necessarily endorsed by the US Army.

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 For the protection of human subjects, the investigator(s) adhered to policies of applicable Federal Law 45 CFR 46.

  
PI - Signature Date

This is the final report for Study NR A-6778 (FY 1995) research supported under the Defense Women's Health Research Program. This paper includes data relevant to gender susceptibility acquired under the two research protocols from their inception to 30 Sep 95.

The issue of gender in decompression sickness (DCS) susceptibility was discussed during a scientific symposium at Brooks AFB, TX in September, 1992 in support of the Presidential Commission on the Assignment of Women in the Armed Forces [ISBN 0-16-038236-X; November 15, 1992]. The background information on DCS presented at the symposium is contained in the introduction of this technical report.

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## ACKNOWLEDGMENTS

This research was sponsored in part by the Armstrong Laboratory, Brooks AFB, TX, USAF Contracts F-33615-92-C-0018, F-33615-89-C-0603, NASA Contract T-82170, and the Defense Women's Health Research Program (Study NR A-6778). We appreciate the editorial support provided by Dr. Sarah A. Nunneley, Dr. F. Wesley Baumgardner, and Mr. Joseph R. Fischer, Jr. of the Armstrong Laboratory Crew Technology Division, Ms. Marion E. Green of the Technical Information Services Division, Dr. Merritt G. Davis of the Hyperbaric Medicine Division, and Dr. Robert W. Krutz, Jr. of KRUG Life Sciences Inc.

## INTRODUCTION

### The Role of Dissolved Nitrogen Gas in Altitude Decompression Sickness (DCS)

At sea level (earth's surface) all tissues are saturated with the partial pressure of nitrogen at the surface (approximately 593 mm Hg; 78% of 760 mm Hg sea level pressure). The ground-level nitrogen saturation results in nitrogen supersaturation in an individual's tissues and blood during decompression. Supersaturation with nitrogen creates a potential for formation of evolved gas emboli (bubbles) resulting in symptoms described as decompression sickness (joint pain, paresthesia, neurologic and respiratory manifestations). Since nitrogen is more soluble in fat tissue than in muscle tissue or blood, a typical female will contain more dissolved nitrogen than a typical male of the same weight due to the female's higher body fat content. Because of this, concern has been expressed about DCS susceptibility of females versus males. No quantitative data comparing denitrogenation rate versus gender were found in the literature.

### Hypobaric versus Hyperbaric Decompression

The basic mechanism of supersaturation and bubble formation is the same under hyper- or hypobaric conditions. Although much of the hyperbaric decompression literature related to the gender issue is pertinent, some differences should be addressed. At the beginning of a scuba dive, the diver is saturated with nitrogen at the surface just as an aviator, but the diver absorbs more nitrogen while breathing at the higher ambient pressure during the dive because the partial pressure of nitrogen doubles at about 33 ft of sea water (fsw), triples at 66 fsw, and so on. Therefore, upon ascent to the surface, the diver becomes supersaturated with nitrogen and begins to deplete that supersaturation with each breath at sea level. The diving and hypobaric decompression situations are, therefore, opposite in one important respect. The scuba diver's situation is most critical at the end of the ascent to sea level, whereas the aviator's situation is most critical during the mission at altitude. The aviator's return to sea level is, in effect, partial treatment for the problem in contrast to the diver whose problem is caused by return to sea level.

Responses to a survey of approximately 700 women divers indicated DCS is more prevalent in females than in males<sup>1</sup>. A conflicting report by Zwingelberg et al.<sup>39</sup> stated "Twenty-eight female students were compared to their 487 male classmates on 878 air and helium-oxygen dives between 120 and 300 fsw. None of the women experienced DCS while 8 men developed DCS symptoms."

### Fetal Susceptibility to DCS and VGE

The issue of fetal susceptibility to DCS becomes pertinent if the mother is exposed to decompression that could evoke fetal gas emboli exclusive of symptomatology in the mother, especially if the mother is unaware she is pregnant. All of the available reports are from hyperbaric exposures and, understandably, none are from experimentation on human fetuses. Bolton<sup>6</sup> surveyed 208 diving-certified females and found that the rate of birth defects following pregnancy in which the mother was an active diver was significantly higher than the incidence rate following pregnancies during which the mother abstained from diving. However, the birth defect rate associated with diving was not different from the the birth defect rate in the general population.

Based on their study of sheep and goats exposed to hyperbaric decompression, Powell and Smith<sup>24</sup> described the fetus as being more at risk than the mother due to normal atrioventricular shunting in the fetal hearts of both sheep and humans. They stated that "All gas bubbles in the fetal circulatory system are potential arterial embolizing agents. Consequently, no "safe bubble limits" can be determined for fetal decompression." This conclusion is pertinent even though fetal gas emboli have been reported to be less prevalent than maternal gas emboli in other animal studies<sup>18,21,22,24</sup>. Several animal studies have found that decompression following exposure to hyperbaric environments and formation of gas emboli has damaging effects on the fetus<sup>12,14,15,19,24</sup>, whereas others have shown no significant effects on the fetus by such exposures<sup>7,21,22,38</sup>. Reports of massive fetal bubbling accompanied by minimal maternal bubbling<sup>12,29,30</sup> have been attributed to the effects of implanting surgery and monitoring techniques<sup>29,30</sup>. Based partly on these reports, a Strategic Air Command (SAC) study<sup>13</sup> recommended that females flying in low-pressure cockpits be screened every 2 weeks for pregnancy and that negative test results be requisite for flight.

### **Retrospective Studies of DCS Based on Altitude Chamber Training Data**

Bassett<sup>2</sup> reported that females, mostly flight nurses, had significantly ( $P < 0.005$ ) greater incidence of DCS than males (0.219% vs 0.022%) in a study of 12,246 altitude chamber training exposures at USAFSAM from 1968 through 1972. Bassett's<sup>3</sup> second report on USAFSAM student altitude chamber exposures covered the period from 1973 through 1977 during which 0.15% of the 9,864 males and 0.54% of the 2,601 females were treated for DCS ( $p < 0.005$ ). Baumgartner et al.<sup>4</sup> reported that females had 2.3 times the DCS incidence of males during the 1985-1987 period. Weien and Baumgartner<sup>37</sup> published a review of 429 cases of DCS resulting from USAF altitude chamber training (1979-1986) that required hyperbaric therapy. The review indicated that the relative risk for females is 4.3 times that for males (0.207% versus 0.048%; 740,505 total exposures;  $p < .001$ ). If the reviews by Bassett<sup>2,3</sup> and Weien and Baumgartner<sup>37</sup> covering the period 1973 to 1986 (1978 missing) are combined, females develop DCS from altitude chamber exposures about 4.6 times more frequently than males (0.224% versus 0.049% based on 765,216 exposures during 1968-1986). Although females appear to have a greater susceptibility than males to develop symptoms of DCS, the 0.224% incidence of symptoms for the 51,713 female training chamber exposures reviewed here is very low, one of each 400+ exposures. The female DCS incidence is, therefore, consistent with World War II data from Cochran<sup>8</sup> indicating none of the 386 Women's Air Force Service Pilots (WASP) exposed to 28,000 ft (4.8 psia; 8,535 m) during a training chamber test experienced symptoms associated with DCS.

Rudge<sup>25</sup> found a linear correlation between time since last menstrual period and decreasing susceptibility to development of DCS, but stated that the underlying mechanism was unknown. The data for this effort came from hyperbaric therapy records on females who developed symptoms during altitude chamber training. Dunford and Hampson<sup>11</sup> also found an increase in susceptibility at the beginning of menses relative to non-menstruating females working as inside attendants during hyperbaric oxygen therapy treatment. However, overall incidence of DCS was similar for male and female inside attendants. Markham et al.<sup>20</sup> reported that platelet aggregability did not change during the menstrual cycle and that gender differences in platelet aggregation were not affected by decompression stress. The question of DCS sensitivity during the menstrual cycle has not been addressed during prospective research chamber studies.

Historical data from training chamber exposure reports are subject to criticism for a number of reasons. Training chamber subject briefings were not fully standardized, allowing different briefings to have different effects on the trainees. Motivation of trainees to report symptoms may be related to their career field which, in turn, determines the type of chamber profile to which they are exposed. Flight nurses were trained using a specific profile not used to train other personnel and were briefed separately. A large majority of the flight nurses took the altitude chamber training course as auxiliary training and did not plan to participate regularly in flight activities. The majority of flight nurses were, consequently, not in jeopardy of losing flight pay if grounded. Therefore, motivation to report symptoms which may result in grounding would have had little effect on most nurses. This may have resulted in more female reports than male reports and biased the susceptibility ratios.

Until 1989, personnel experiencing neurologic DCS symptoms were usually grounded permanently and even mild limb pain DCS symptoms during chamber training were cause for fear of grounding in the mostly male aircrew population. Pilot trainees, being highly motivated to avoid grounding, contrast greatly in motivation to report symptoms with many of the flight nurses who received chamber training from 1968 to 1986. Hence, the gender difference in DCS incidence during training chamber exposures may actually be more a function of reporting than of physiologic differences related to gender. This is upheld by the paucity of official reports of DCS in the U-2 community despite high levels of reporting when anonymity was assured<sup>5,23</sup>.

In 1994, the policy on DCS waivers changed. AFI 48-123<sup>1</sup> now states that "History of Decompression Sickness (DCS) does not require a waiver." It further states that "In cases of DCS with neurological manifestations, a normal examination by a neurologist is required before RTFS" [return to flying status]. The previous policy of automatic grounding for neurologic manifestations with the possibility of a waiver did little to promote complete reporting of DCS. The change may eventually promote more accurate reporting.

### **Treatment of DCS Symptoms Resulting from Altitude Chamber Exposures**

When crewmembers have symptoms of DCS that are not resolved by returning to ground level, hyperbaric oxygen therapy is the accepted treatment<sup>9,37</sup>. Davis et al.<sup>9</sup> reported that 20 of the 145 persons treated for DCS were female and mentioned that females presented "some of the more complicated cases for medical management during therapy" although the female case reports included in the paper indicated rapid and complete clearing of all symptoms during standard treatment. Bassett<sup>3</sup> noted that the females with DCS appeared slender and presented more recurrences and neurological defects following hyperbaric therapy. It is unknown how many of these same cases may have been discussed by Davis et al.<sup>9</sup> due to overlap of reporting period. Rudge and Shafer<sup>26</sup> reported on 233 cases of altitude chamber DCS treated in USAF hyperbaric chambers and found that "outcome of treatment was not significantly related to patient age, sex, or type of symptoms." Weien and Baumgartner<sup>37</sup> did not report any gender difference in their study of hyperbaric therapy results from 528 DCS cases.

In an effort to understand what appears to be a difference between female pilots and female flight nurses with respect to DCS susceptibility, we completed a retrospective analysis of computerized records of hyperbaric oxygen treatment resulting from over 19,000 training chamber exposures accomplished by pilot trainees who completed USAF pilot training from 1978 to 1991. Over 550 of

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<sup>1</sup> Attachment 6; page 172; 15Nov1994

those pilots (2.75%) were females. Each pilot trainee completed two altitude chamber training exposures during the first portion of their pilot training program. None of these pilots, male or female, were treated with hyperbaric oxygen therapy for DCS symptoms acquired during the pilot training chamber exposures. However, any pilot trainee with symptoms would have been given ground-level oxygen until arrival at a hyperbaric treatment facility. Since no hyperbaric treatment facilities were co-located with pilot training bases during that time period, the time delay between report of symptoms and initiation of treatment would likely have been at least two hours. During that time, most or all of the symptoms from such an exposure could have resolved; hence no record of hyperbaric oxygen treatment. Furthermore, here again, concern of these pilot trainees about potential grounding may have contributed to the lack of reports.

### **Hypobaric Research Chamber Studies**

Although more dissolved nitrogen may imply greater need for denitrogenation in females, the few research hypobaric chamber studies do not indicate that gender is a significant factor in susceptibility<sup>16,31</sup>. Most of the available data gathered from research using defined (prospective) protocols to investigate gender-related susceptibility to DCS has been accomplished at USAFSAM (now the Armstrong Laboratory)<sup>32,17</sup>. Smead et al.<sup>27</sup> and Webb et al.<sup>36</sup> reported on different aspects of a study that exposed 20 males and 11 females to 15,000 ft (8.3 psia; 4,572 m) for 6 hours. No statistical gender difference was found in incidence of DCS or venous gas emboli (VGE). In studies at NASA-JSC that involved 67 exposures to pressures of 6.0 psia (22,800 ft, 6,950 m) and 4.3 psia (30,000 ft, 9,144 m) with staged decompression or 6 hours of prebreathe, Waligora et al.<sup>31</sup> found no statistical difference in the incidence of symptoms or venous gas bubbles between males and females.

Webb et al.<sup>33</sup> found that no VGE or symptoms of DCS were present in the 10 female and 11 male subjects exposed to 11,500 ft (9.5 psia; 3,505 m) while breathing 100% oxygen for 8-h periods on five consecutive days. Dixon et al.<sup>10</sup> found that exposures of 30 males and 30 females to 16,500 ft (7.8 psia; 5,029 m) breathing 50% oxygen and 50% nitrogen resulted in no significant differences in incidence of DCS at the  $p = .05$  level, but did report that males produced more VGE ( $p < .025$ ).

While breathing air or breathing the oxygen-enriched mixture delivered by a USAF narrow panel regulator set to NORMAL, denitrogenation is minimal<sup>34</sup>. Severe VGE<sup>2</sup> have been observed in about one-fourth of both male and female subjects<sup>32</sup> exposed to altitudes as low as 15,000 ft (8.3 psia; 4,572 m) while breathing 50% nitrogen and 50% oxygen. The percentage of subjects who develop severe VGE during a research chamber exposure is an indication of the relative severity of the exposure in the absence of DCS.

### **Operational Incidence of Altitude DCS**

Prior to development of pressurized cabins in transport and bomber aircraft, Cochran<sup>8</sup> reported no decompression-related problems in a report summarizing about 600,000 flying hours achieved by a group of over 1,000 female pilots during World War II. Recent studies comparing operational incidence of DCS between genders are almost non-existent due to the rarity of female exposure to operational decompressions. However, future tactical fighter aircraft may cruise at 60,000 ft (1.1 psia;

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<sup>2</sup> VGE Grades 3 & 4 (Spencer Scale<sup>28</sup>) are defined here as severe VGE. Armstrong Laboratory records on 119 exposures to 29,500-30,000 ft (approximately 4.5 psia; 8,930 m) show that over 95% of the exposures resulting in VGE and DCS had Grade 3 or 4 VGE. Grade 1 or 2 VGE are, therefore, not considered severe.

18,288 m) for sufficient time to evoke symptoms in a significant percentage of the crewmembers. Many other aerospace combat roles including airdrop, gunship operations, and their associated training scenarios present an altitude challenge. The inclusion of females in most of these combat roles places them in aircraft where DCS incidence in their male counterparts is presently of concern.

The operational level of DCS symptom risk to female crewmembers is currently unknown and requires definition to ensure adequate protection and training. A prospective research program at the Armstrong Laboratory has been initiated to answer the gender susceptibility question using standardized research chamber methodology.

## METHODS

Two protocols approved by the Armstrong Laboratory Advisory Committee on Human Experimentation (AL ACHE) and the USAF Surgeon General were used to obtain data: AL ACHE Protocol #93-03A entitled, "Decompression sickness protection below 25,000 ft using 100% oxygen without prebreathe," and AL ACHE #91-19 entitled, "Decompression Sickness (DCS) Protection Using a 100% Oxygen Pressure Suit Environment."

### Subjects

Subjects (nonsmokers for the preceding 2 years) participating in the two protocols comprising this study<sup>3</sup>, were exposed to the altitudes/pressures shown in Table I. The voluntary, fully-informed consent of the subjects used in this research was obtained in accordance with AFI 40-402. All subjects passed an appropriate subject physical examination, and were otherwise representative of the USAF rated aircrew population. They were not allowed to participate in SCUBA diving, hyperbaric exposures, or flying for at least 36 h before each scheduled altitude exposure. Each subject was exposed one time and was not informed of the exposure altitude, except that it was below 25,000 ft.

**TABLE I. Exposure Altitudes and Number of Subjects Exposed**

Altitude, ft	Meters	psia	mm Hg	Subject Gender/N	
				Male	Female
15,000	4,572	8.3	429	10	
16,500	5,029	7.8	404	8	
18,100	5,517	7.3	378	10	10
19,800	6,035	6.8	352	10	10
21,200	6,462	6.4	333	17	
22,500	6,858	6.1	314	18	2
23,800	7,254	5.7	297	10	

<sup>3</sup> During FY 1995, 31 male and 5 female human experimental subject exposures were accomplished.

## Methods and Experimental Procedures

Prior to each altitude exposure, the medical monitor conducted a short physical examination of subjects to identify any signs of illness or other problem which would endanger the subject or bias the experimental results. In addition, each subject was taken to 5,000 ft (12.2 psia; 1,524 m) simulated altitude in the altitude chamber at a rate of 5,000 ft/min for an ear and sinus check. Time spent at 5,000 ft was less than 5 seconds. During the return to ground level at 5,000 ft/min, the inside observer ensured that subjects were able to equalize the pressure across their eardrums.

A neck-seal respirator made by Intertechnique® (Plaisir Cedex, France) was used for oxygen delivery because it provided a slight, 2 cm of water, positive pressure which reduced the opportunity for inboard leaks of nitrogen from the atmosphere. This respirator is also more comfortable than the standard aviator's mask. Two full inspiration/expiration cycles with 100% oxygen were completed immediately after donning the mask and just prior to ascent to reduce the nitrogen concentration in the mask and in the conducting airways. Breathing gas for ascent and altitude exposure was 100% oxygen (aviator's breathing oxygen; normal analysis 99.7-99.8% oxygen). The subjects were decompressed at 5,000 ft/min and remained at altitude for 6 h (Table I).

Lack of availability of female subjects precluded enough exposures at the higher altitudes to allow statistical analysis of DCS incidence versus gender. The greater availability of male subjects allowed use of males to establish the threshold of VGE. This was followed by addition of female subjects at 18,100 and 19,800 ft where the male subjects exhibited substantial levels of severe VGE.

During each exposure, the subjects performed three sets of mild exercise each h simulating EVA activities. The arm exercises each lasted 4 min: 1) Hand-cranked cycle ergometer (24 rpm; 4 Newtons); 2) Torque wrench (25 ft-lbs for 5 sec each position); 3) Rope pull (resistance of 17 kg). To provide relief from boredom and more closely emulate operational distractions, action-oriented videos were shown to the subjects during the hypobaric exposures.

A Hewlett-Packard® SONOS 500 or 1000 Echo Imaging System (Andover, Massachusetts) recorded both visual and auditory VGE signals. Three VGE-monitoring sessions were accomplished each h. The subjects lay on a horizontal examining table on their left side. The ultrasound probe, via a pass-through the chamber wall, was positioned at the subject's third intercostal space on the left side for a parasternal, short-axis view of the heart. This view allowed clear observation of all four chambers of the heart while the probe was aimed at the apex of the right ventricle. The echo-image provided guidance and visual feedback for probe orientation to allow reception of the best image and ultrasound signals. Sequential articulation of each limb during the observation period facilitated movement of VGE to the vena cava and right atrium. VGE detected with this system are graded according to the Spencer Scale<sup>28</sup>. Using this scale, severe VGE were designated as grade 3 or 4 VGE which means that VGE were present during over half of all heart cycles observed. The use of severe versus any VGE in reporting incidence is related to the severity of consequences associated with the subdivision of grades (see footnote 2 on page 8). This includes a hypothesized potential for adverse reaction following further decompression with severe versus lower levels of VGE.

## Endpoints

Endpoints of the exposures were: 1) completion of 6 h at altitude; 2) development of DCS signs or symptoms such as neurological, peripheral, or respiratory; or 3) development of Grade 2 DCS joint pain. DCS joint pain was graded as follows: Grade 1) intermittent, mild to moderate pain, intermittent or constant joint awareness or "fullness"; Grade 2) constant, tolerable, mild to moderate pain<sup>35</sup>. Subjects were not questioned about how they felt during the altitude exposures. However, they did receive a briefing on the morning of each exposure which emphasized their responsibility to report any DCS symptoms to chamber personnel. Since the motivation to report symptoms should be equal for all subjects in this research study, a better estimation of any gender-dependent differences in susceptibility should also become available.

## Analysis of data

Chi Square Tests were performed to determine existence of differences in DCS incidence and severe VGE incidence between genders and altitudes where comparisons were possible (18,100 ft and 19,800 ft; 7.3 and 6.8 psia; 5,517 and 6,035 m). Since only two of the female subjects were exposed to altitudes above 20,000 ft (<6.75 psia; >6,096 m), no analyses of that data were attempted.

## **RESULTS**

One of the 10 female and none of the 10 male subjects developed symptoms of DCS at 19,800 ft (6.8 psia; 6,035 m). None of the 10 female or 10 male subjects developed symptoms of DCS at 18,100 ft (7.3 psia; 5,517 m). None of the 10 males exposed to either 15,000 ft (8.3 psia; 4,572 m) or 16,500 ft (7.8 psia; 5,029 m) developed symptoms. Only two females were exposed to altitudes above 20,000 ft (<6.75 psia; >6,096 m), obviating ability to perform statistical analysis for susceptibility differences, although neither developed DCS symptoms. The DCS incidence below 20,000 ft (>6.75 psia; <6,096 m) was not significant.

The severe VGE incidence at 18,100 ft (7.3 psia; 5,517 m) and 19,800 ft (6.8 psia; 6,035 m; Fig. 1) showed a trend, although not significant, indicating more severe VGE in males than in females exposed to the same altitude. A summary of the severe VGE incidence in males from 11,500<sup>4</sup> to 23,800 ft (9.5-5.8 psia; 3,505-7,254m; Fig. 2) reflects the increase in severity of exposure despite the lack of DCS symptoms.

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<sup>4</sup> Data on 11,500 ft exposures from Webb et al. (33)

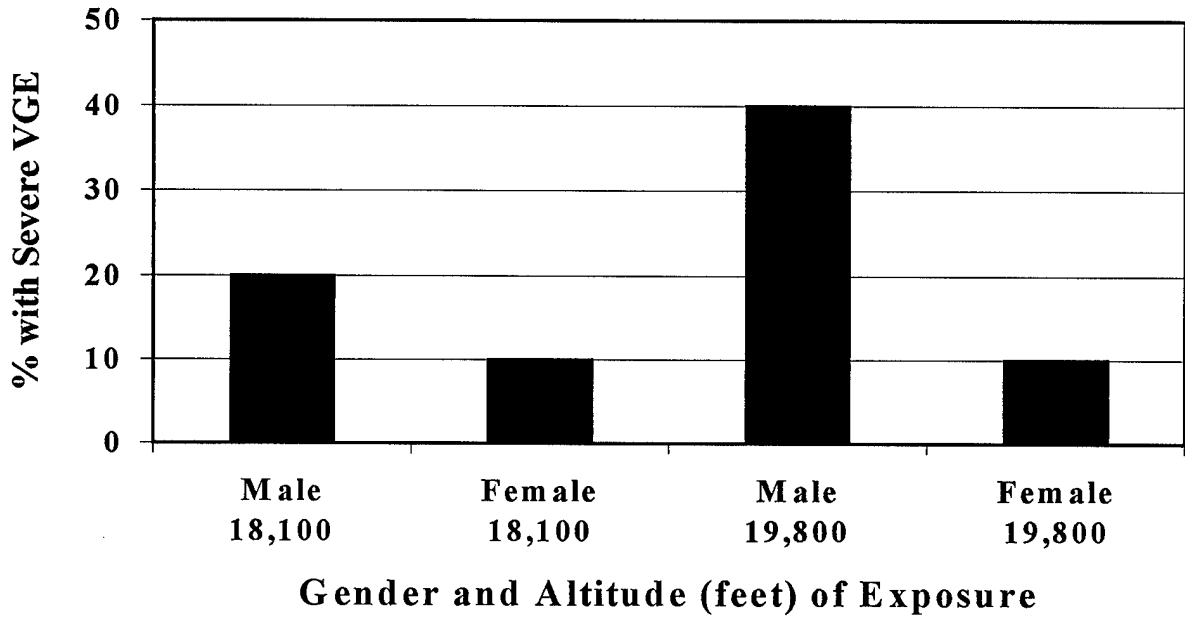


Figure 1. Male versus Female Severe VGE

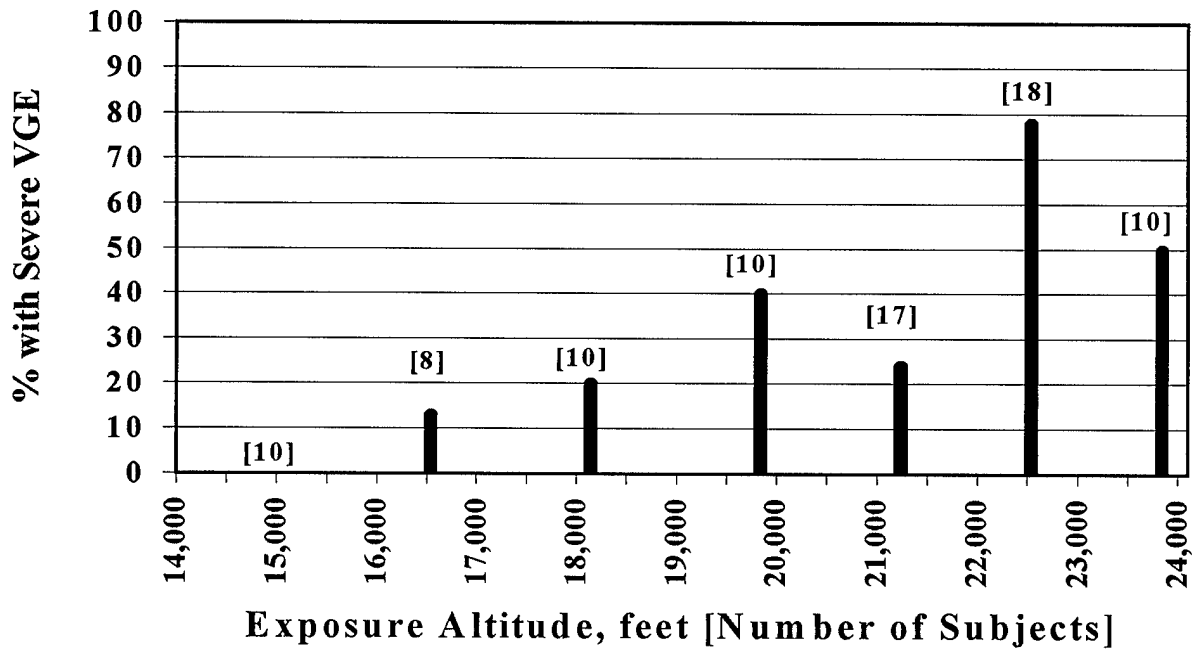


Figure 2. Male Severe VGE versus Altitude

## DISCUSSION

The exposures at lower altitudes were designed to show the altitude threshold of both severe VGE and DCS. We expected to observe substantial levels of VGE and DCS at altitudes below 20,000 ft (>6.75 psia; <6,096 m) since previous research using a mixed breathing gas, 50% nitrogen: 50% oxygen, yielded considerable severe VGE (25%) at 15,000 ft (8.3 psia; 4,572 m) and some DCS (<15%) at 15,000 ft and 16,500 ft (7.8 psia; 5,029 m)<sup>32,34</sup>. The available female subjects were exposed to altitudes where we anticipated sufficient levels of DCS to enable comparison with male subjects and to reveal the female DCS threshold. Since none of the males and only one of the females developed DCS symptoms, it is apparent that the threshold for substantial levels of DCS is higher than we anticipated.

The trend toward higher levels of severe VGE in males versus females (Fig. 1) is consistent with the report by Dixon, et al.<sup>10</sup> At 16,500 ft (7.8 psia; 5,029 m) males produced more VGE than females. However, another report<sup>32</sup> indicated virtually identical levels of severe VGE in male and female subjects at 15,000 ft (8.3 psia; 4,572 m).

Comparative research chamber data on gender differences in altitude-induced DCS susceptibility are very limited, particularly above 20,000 ft (<6.75 psia; >6,096 m) where training chamber gender susceptibility differences were reported. No statistical comparison could be made of DCS susceptibility due to the low number of female subjects exposed at the altitudes where DCS was common in male subjects. Further research comparing responses of male and female subjects at simulated altitudes above 20,000 ft (<6.75 psia; >6,096 m) could clarify the risk for pilots in future high-altitude combat aircraft and is underway at the Armstrong Laboratory. If gender differences are found, they should be evaluated relative to their impact on equipment design, mission accomplishment, and ability to compensate by modification of mission parameters such as length of prebreathe, climb profiles, or length of exposure.

### Recommended Restrictions During Pregnancy

Based on normal fetal atrioventricular shunting, fetuses should be protected from exposure to physiologically significant gas emboli. While breathing a 50% nitrogen:50% oxygen breathing gas, severe VGE were observed at 15,000 ft (8.3 psia; 4,572 m) in female subjects<sup>32</sup>. Even while breathing 100% oxygen, severe VGE were observed during this study at 18,100 ft (7.3 psia; 5,517 m) in female subjects and could be indicative of hazard to a fetus. During pregnancy, females should, therefore, be restricted from flights or chamber training where the cockpit or chamber altitudes exceed 10,000 ft (10.1 psia; 3048 m) while breathing mixed gas, or 15,000 ft (8.3 psia; 4,572 m) while breathing 100% oxygen. These restrictions should prevent formation of severe VGE in any pregnant female, reducing the potential hazard to the fetus.

## CONCLUSIONS

No significant differences in levels of DCS or VGE were found in the 10 female and 10 male subjects exposed to 18,100 ft (7.3 psia; 5,517 m) or in the 10 female and 10 male subjects exposed to 19,800 ft (6.8 psia; 6,035 m). Due to the low sample size completed during this phase of the research, no policy decisions should be based on the lack of significant difference in DCS incidence. Increased severity of VGE in males over the altitude range of 15,000 ft to 19,800 ft (8.3 psia to 6.8 psia; 4,572-

6,035 m; N = 38) reflects the increased severity of exposure. Further female subject exposures are needed above 20,000 ft (<6.75 psia; >6,096 m) to determine the female threshold of DCS under the study conditions.

Results of VGE observations, previous reports on VGE occurrence, and fetal physiology imply that protection of the fetus from the effects of VGE is necessary. During pregnancy, females should be restricted from flights or chamber training where the cockpit or chamber altitudes are planned to exceed 10,000 ft (10.1 psia; 3048 m) while breathing mixed gas, or 15,000 ft (8.3 psia; 4,572 m) while breathing 100% oxygen.

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