CASE REPORT

Decompression Sickness Rates for Chamber Personnel: Case Series from One Facility

MEGAN S. BRANDT, THOMAS O. MORRISON, AND WILLIAM P. BUTLER

BRANDT MS, MORRISON TO, BUTLER WP. ***Decompression sickness rates for chamber personnel: case series from one facility.*** **Aviat Space Environ Med 2009; 80:570–3.**

During 2004, a case series of decompression sickness (DCS) meeting the definition of epidemic DCS was observed in the Shaw AFB Physiological Training Program. There were 10 cases of chamber-induced altitude DCS observed. Internal and external investigations focused on time, place, person, and environment. No temporal trend was observed. Chamber, masks, regulators, crew positions, and oxygen sources revealed no defects. Among the cases, mean age was 27 yr. Peak altitude in four cases was 35,000 ft and in the other six cases was 25,000 ft. Six had joint pain, one skin symptoms, and three neurological findings. Four were treated with 100% ground-level oxygen and six with hyperbaric oxygen. Four were students and six were inside observers (IO). Four were women and six men. In the IO, where four of the six were women, no gender effect was seen. Examining the IO monthly exposure load (exposures per month) against DCS suggested a dose-response relationship. This relationship held true when 4 yr of Shaw AFB IO data was studied. Indeed, Poisson regression analysis demonstrated a statistically significant 2.1-fold rise in DCS risk with each monthly exposure. Consequently, the number of exposures per month may need to be considered when devising IO schedules.

Keywords: decompression sickness, DCS, inside observer, IO, epidemic, cluster, dose-response, exposures per month.

DECOMPRESSION sickness (DCS) as a consequence of altitude chamber training is a relatively uncommon occurrence. In 1977, Davis et al. quoted a 0.0010 incidence (1 case in 1000 exposures) for the USAF (3). Since then, a number of authors have reported an incidence ranging from 1 in 10,000 to 2+ in 1000 (1,7,11). At the same time, outbreaks of DCS have been intermittently reported (2,6). In fact, two forms have been described—population-based with cases happening over a defined time period and individual-based with cases happening from a solitary exposure (2). There are at least seven separate well-documented instances of so-called epidemic DCS found in the literature (2,6,9).

During Fiscal Year 2004 (FY04), an epidemic of DCS was recorded at the Shaw AFB, SC, Physiologic Training Program. All cases of DCS resulted from altitude chamber training, which is preventative in nature. While flying military aircraft above 10,000 ft, detection of oxygen equipment malfunction or a slow decompression may well be dependent on the recognition of personal hypoxia symptoms. Inability to identify hypoxia symptoms early enough to correct the hypoxic state could well result in tragedy. Of note, all training is conducted specific to the aircrew mission (i.e., fighter vs. larger cargo aircraft). Depending on airframe concerned, hypobaric chamber peak altitudes range from 25,000 to 35,000 ft.

The hypobaric chamber at Shaw AFB was manufactured in 1953 and has functioned well since that time. The chamber holds 16 students and 3 inside observers per flight. In an average year, the training program runs 110+ hypobaric training "flights." More than 900 students are trained annually.

Over this 12-mo period, 10 cases of DCS were diagnosed and treated. As a result, an internal and external outbreak investigation was conducted. Although no specific etiology was indicted, an interesting and previously unreported relationship between the number of exposures per month (in inside observers, IO) and DCS was detected. This report describes that relationship.

CASE REPORT

During FY04, 10 cases of chamber-induced altitude DCS were observed. This series of cases met the definition of epidemic DCS: diagnosis of DCS defined by exposure and relevant symptoms, four or more cases of DCS, and an incidence above baseline (2). Of the 10 cases, 8 were clearly DCS (the other 2 will be discussed later); there were more than 4 cases; and there was better than a fourfold rise in DCS incidence (see specifics below). Thus, the definition for a case of epidemic DCS was met. Furthermore, since there was not a single responsible exposure, this was deemed a case of population-based epidemic DCS and a traditional outbreak investigation was commenced (2). The inquiry followed the standard focus of an infectious disease outbreak—time, place, person, and environment.

From the 20th Medical Group, 20th Aeromedical-Dental Squadron, Aerospace Training Physiology Flight, Shaw AFB, SC, and the Department of Preventive Medicine and Biometrics Division of Aerospace Medicine, Uniformed Services University of the Health Sciences, Bethesda, MD.

This manuscript was received for review in September 2008. It was accepted for publication in March 2009.

Address reprint requests to: William P. Butler, Col, USAF, MC, CFS, Deputy Commander, 18th Medical Group, PSC 80, Box 10265, APO AP 96367-0005; william.butler@kadena.af.mil.

DOI: 10.3357/ASEM.2438.2009

Time

For the 4-yr period, October 2000 through August 2004, a chamber record review was conducted. The monthly reports for 3646 students and IO were examined. There were 14 cases of DCS discovered, 10 during FY04. April and May each had three cases recorded while no cases were recorded in November, December, or January (the data did not permit rate calculations by month). No temporal trends were detected either during FY04 or in combination with the prior 3 yr. Incidence rates for each year were 0.0015 for FY01, 0.0020 for FY02, 0.00 for FY03 (unfortunately, the student exposure data was incomplete for FY03), and 0.0091 for FY04; the difference was statistically significant ($P < 0.05$, Chi square with Yates' correction).

Place

Extensive visual and functional maintenance inspections found no operational discrepancies. An operator's checklist was completed daily; this checklist identified the main working elements of the chamber, including the main pump, chamber exterior/interior, oxygen manifold, and valve control. In addition to the daily inspections (e.g., checklist), after every 200 chamber flight hours, a detailed periodic and/or specified inspection was conducted in accordance with Technical Order 43D8-3-2-6. All chamber masks were inspected visually every 30 d and, after every 90 d, each mask was disassembled for a more thorough internal inspection. Equipment inspections also included regulators, oxygen sources, and crew consoles. Interestingly, IO Position #1 was associated with the four female cases and IO Position #3 was associated with the two male cases; no equipment problems were identified. During both the internal and external investigations, the chamber and its systems along with its program of operation were found to be within standards.

Person

In the 10 cases of DCS, the mean age was 27 yr (ranging from 19–39 yr). Six were men and four were women. Four were students and six were IO. Maximum altitude in four cases was 35,000 ft and in the other six was 25,000 ft. Joint pain was the most common symptom, in particular right shoulder pain. Three had well-defined peripheral neurologic findings—the two female IO were treated with U.S. Navy Treatment Table 6 (TT6) and the one male student was treated with 100% ground-level oxygen (GLO). This student had paresthesias along the left little finger essentially defining a very distal ulnar nerve involvement. Although he was successfully treated with GLO, an argument for a TT6 could easily be made and is recommended by USAF guidelines. Two students experienced tingling and grayed vision at altitude suggestive of hypoxia/hyperventilation. They may well have been symptomatic from hypoxia/hyperventilation rather than DCS; however, the on-scene physicians diagnosed DCS. In these two cases, symptoms dissipated prior to reaching ground level. They were treated with 100% oxygen; hyperbaric oxygen was not required. The fourth student was successfully treated with GLO and the six IO were successfully treated with hyperbaric oxygen therapy using TT6. Of note, the four student cases seen in the preceding three years also required TT6. **Table I** characterizes not only the FY04 cases of DCS, but also the previous 3 fiscal years. Other factors that did not demonstrate trends among these cases include obesity, alcohol intake, lack of sleep, hydration, preflight exercise, and medications. Generally speaking, all cases were relatively young, in reasonable physical condition (eight successfully passed fitness testing, one failed, four were unknown, and one was activity restricted), and all but one presented within 24 h of exposure (that IO presented at ~72 h after exposure). No obvious trends were seen with exposure altitude, type of DCS, or symptoms.

Since there were four women who developed DCS, it was felt that this might be a factor. Each of the four women was an IO. A female to male DCS rate ratio of 2.13 to 1 was seen. But this predominance was not statistically significant ($P > 0.05$, Chi square with Yates' correction).

Attention then focused on the IO vs. students. There were 6 cases of DCS in 323 exposures for the IO and 4 cases in 780 exposures for the students, describing an IO to student DCS rate ratio of 3.22 to 1 (0.0186 vs. 0.0051). Although this was not statistically significant ($P = 0.07$,

TABLE I. FISCAL YEARS 2001-2004—DESCRIPTIVE CHARACTERISTICS OF DCS CASES.

			Time Between Exposure & Symptoms	Exposure		Symptoms			DCS		Treatment	
Fiscal Year	Status	Gender	(mean hours)	FL250	FL350	Joint Pain	Skin	Neurologic	Type I	Type II	GLO*	TT6*
2004	Inside	Female	4	1	3	3	1	2	2	2	–	4
	Observers	Male	36§	2	–	2	–	–	2	–	–	2
	Students	Male	during exp	3	1	1	–	3†	4†	–	4†	–
2002	Students	Male	4	–	1	3	–	–	2	1‡	–	3
2001	Students	Male	16	3	–	1	–	–	1	–	–	1
Totals		4 f: 10 m		9	5	10	1	5	11	3	4	10

* GLO = 100% ground level oxygen; TT6 = USN Treatment Table 6.
† Two cases may have been hypoxia-hyperventilation; however, attending physicians diagnosed DCS.
‡ Despite joint pain being the sole symptom, this case was classified at the time as Type II.
§ There were two male IO; symptoms began at 20 min in one and at 72 h in the other.

Chi square with Yates' correction), it was suggestive. After eliminating the two questionable DCS student cases, the IO predominance jumped to 7.15 to 1 (0.0186 vs 0.0026), which was statistically significant.

Environment

For FY04, exposures per month for each IO could be determined. In addition, DCS could be cross-referenced to the exposures per month (a.k.a. monthly workload). As a result, DCS rates for exposures per month could be calculated. With each added exposure per month there appeared to be a rise in the DCS rate. This prompted examination of the entire 4 yr wherein chamber reports produced excellent IO exposure data. **Table II** delineates these observations.

Once again, with each added monthly exposure the DCS rate rose. At four exposures per month, the rate began an abrupt rise that seemed to increase exponentially at five exposures per month. A logarithmic plot of these rates demonstrated a linear "dose-response" like relationship. Employing Poisson regression analysis, the relative risk of DCS was found to increase by a factor of 2.1 with each added monthly exposure (using SAS; 95% confidence interval: 1.20, 3.61; $P = 0.009$).

Internal/External Investigations Recommendations

IO Position #1 was replaced; analysis of the removed equipment revealed no abnormality. The potential for IO mask leak was essentially eliminated by breathing on the "emergency" setting—pressurized oxygen breathing. An oxygen analyzer was installed to verify oxygen purity prior to every chamber flight as purity must be maintained at or above 98%. Weekly calibration of the analyzer was mandated. Scheduling more than three chamber exposures per month was avoided. A tracking spreadsheet was devised to aid scheduling. Since these measures were implemented, no further DCS has been observed in IO.

DISCUSSION

In this article, we report a case of population-based epidemic DCS. This prompted an inquiry patterned after the standard infectious disease outbreak investigation. Our investigation led to a focus on the IO.

TABLE II. DCS RATES AS RELATED TO EXPOSURES/MONTH.

Exposure Load (Exposures/Month)	Months of Exposure Load	Cases of DCS	DCS Rates (%)*
0†	214†	0†	–†
1	269	1	0.4
2	165	2	1.2
3	108	0	–
4	38	1	2.6
5	13	2	15.4
> 5	3	0	–

* DCS Rates (%) = (Cases of DCS/Months of Exposure Load) x 100.
† Zero Exposures/Month Exposure Load is reported to define the number of months where IO had no risk for DCS. It was not a data point used in the Poisson regression analysis.

Four IO were women and all were within 10 d of their menses. It is sometimes held that women are more susceptible in the early days following menses; this is controversial and not supported in all the literature. Both Rudge and Webb et al. have documented this observation (8,10). Indeed, Webb et al., using research subjects, demonstrated that those on hormonal contraception demonstrated similar susceptibility within the first 2 wk of menses, but in the 2 wk prior to menses DCS incidence rose well above those women not on contraception. Interestingly, our four women were taking contraceptives. Furthermore, Webb et al. found an inverse gender-age relationship; that is, as age rises, DCS incidence in males increases while that in females drops. We found a similar relationship—mean age for the six men (30.7 yr) exceeded that for the four women (21.8 yr) by almost 9 yr. It was even more pronounced in the FY04 IO (men = 36.5 yr and women = 21.8 yr). However, like Webb et al. we were unable to demonstrate any clear female predominance, suggesting that gender was not a factor in this outbreak or that the numbers were too small to establish gender as a factor.

Students are trained routinely every 5 yr whereas IO generally have at least one exposure per month and, in our epidemic, some of the affected individuals had up to seven exposures in a given month. Davis et al. and Bason et al. found the IO to student DCS rate ratio to be higher—3.2 to 1 and 12.7 to 1, respectively (1,3). Weien et al. and Rice et al. found no such relationship; they reported DCS rate ratios of 1 to 1 and 1 to 1.5, respectively (7,11). In our epidemic year, FY04, we found the rate ratio to be 3.2 to 1.

Furthermore, we discovered that DCS in IO increased with the monthly workload. Indeed, we found that not only was there a dose-response relationship, but there was also a statistically significant rise in risk with each monthly exposure. In fact, risk of DCS rose 2.1-fold with each monthly exposure ($P = 0.009$, Poisson regression analysis).

Although this relationship has not been previously reported in IO, it has been observed. During the Operation Everest II research project, the rate of DCS "appeared related to frequency of exposure, severity of altitude, and physical activity" (4). This was a 40-d study where 8 subjects underwent 1-10, 11-20, 21-30, or 31-40 altitude exposures (total of ~1265 h); rates of DCS were 9.5%, 3.4%, 17.1%, and 30.7%, respectively. Overall, there were 28 cases of DCS over 274 exposures (10.2%). Clearly, these researchers demonstrated a dose-response relationship.

Oft quoted, but not pertinent here, Pilmanis et al. showed that repeated exposures significantly reduced the DCS rate (5). In their experiment, subjects underwent two repeated-exposure protocols—four 30-min exposures without a ground-level interval (Group B) and four 30-min exposures with a 60-min ground-level interval (Group C); all were taken to 25,000 ft. The rate of DCS for controls (Group A) was 59%, for Group B 22%, and for Group C 6%. While interesting, their exposure frequency profiles did not resemble those of operational IO in the slightest, thus making any comparisons non-relevant.

There is no easy explanation for our observation or that from Everest II. Bason et al. submit that altitude exposures induce hemodynamic changes such as reduced platelets, increased fibrinogen, and increased enzymes that may possibly increase susceptibility to DCS (1). They further suppose that these changes probably do not revert to normal for at least 3-4 d (1). To date, no ready evidence supports this hypothesis; however, it would explain both our findings and that of Operation Everest II. In any event, the observation seems real in these two instances and should certainly be studied further. Until then, this potential dose-response relationship should be considered when scheduling IO exposures so that excessive exposures per month are avoided.

ACKNOWLEDGMENT

Authors and affiliations: Megan S. Brandt, B.S., 31st Aerospace Medicine Squadron, Human Performance Training Flight, Aviano AB, Italy; Thomas O. Morrison, B.S., M.S., 19th Aerospace Medicine Squadron, Little Rock AFB, AR; and William P. Butler, M.D., MTM&H, 18th Medical Group, Kadena AB, Okinawa, Japan.

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