The Effectiveness of Ground Level Oxygen Treatment for Altitude Decompression Sickness in Human Research Subjects

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**Background:** Current therapy for altitude decompression sickness (DCS) includes hyperbaric oxygen therapy and ground-level oxygen (GLO). The purpose of this paper is to describe the Air Force Research Laboratory experience in the extensive use of GLO for the treatment of altitude DCS in research subjects. **Methods:** Data were collected from 2001 altitude chamber subject-exposures. These data, describing DCS symptoms, circulating intracardiac venous gas emboli, and treatment procedures used were collected for each subject exposure and stored in an altitude DCS database. **Results:** In the database of 2001 subject exposures, 801 subjects (40.0%) were diagnosed with altitude DCS. Subjects reporting DCS symptoms were immediately recompressed to ground level. Of the 749 subjects who received 2 h GLO, 739 (98.7%) resolved completely and required no further treatment. **Conclusions:** Although not an operational study, these data provide indirect support for the current USAF guidelines for the treatment of altitude DCS with GLO. **Keywords:** decompression sickness; treatment; oxygen.

**METHODS**

Data were collected from altitude chamber subject exposures at Brooks AFB from January 1983 through July 1998. These data, describing DCS symptoms, circulating intracardiac venous gas emboli (VGE), and treatment procedures, were collected for each subject-exposure and stored in an ongoing computerized altitude DCS database. There were 399 subjects who participated in 2001 exposures over this time period. All subjects passed the appropriate subject physical examination, and were representative of the USAF rated aircrew population in terms of age, height, and weight. Informed consent was obtained from each subject and the use of human subjects for all exposures was approved locally by the Advisory Committee for Human Experimentation and by the USAF Surgeon Generals.
Office according to USAF AFI 40–402. These exposures were part of several research studies designed to investigate various aspects of altitude DCS such as the effect of exercise, preoxygenation schedules, sex, and age. The altitude of the exposures ranged from 2,743–10,668 m (9,000–35,000 ft). Preoxygenation duration ranged from 0–240 min. Activity at altitude ranged from rest to heavy exercise. The experimental endpoints, however, were consistent throughout all of the subject exposures, and were as follows:

1. A time limit, as set by the study, had elapsed. This limit typically ranged from 3–6 h at simulated altitude.
2. The subject experienced symptoms of DCS. If the symptom was joint pain, the pain was required to be constant in character, so as to minimize confusion with spurious aches.
3. A medical condition other than DCS occurred.
4. The subject requested termination of the experiment.

It is important to note that, based on these endpoints, we are describing the treatment of the initial symptoms of altitude DCS under controlled experimental conditions.

Non-invasive monitoring for VGE was done with echocardiography using Hewlett Packard SONOS 500 or 1000 Echo Imaging Systems. This method provides both visual images and audio Doppler of circulating intravascular bubbles, which are used as semi-objective measures of decompression. However, VGE scores were not used as an end-point for the exposures (10). The 5-point Spencer Scale for grading VGE was used (9).

Subjects reporting DCS symptoms were immediately recompressed to ground level. All exposures were attended by a medical monitor (with no involvement in the research protocol), who determined the disposition of the research subject: either GLO or referral to Hyperbaric Medicine Division immediately adjacent to the altitude chamber. In general, subjects presenting with pain, paresthesia, and/or skin symptoms of DCS that resolved completely on descent were treated with GLO. Subjects with neurologic and/or respiratory symptoms or pain, paresthesia, and/or skin symptoms that persisted at ground level, were referred to Hyperbaric Medicine. However, the final determination of course of treatment was at the discretion of the medical monitor and the Hyperbaric Medicine staff. Treatment with GLO was considered successful if symptoms resolved completely during descent or during GLO treatment and no further symptoms were reported.

RESULTS

In the database of 2001 subject exposures, 801 (40.0%) resulted in altitude DCS. All symptoms resolved and no sequelae have been found. Fig. 1 breaks down the treatments used and the treatment results for all DCS cases. Of the 801 cases of DCS, 794 (99.1%) of the initial symptoms occurred at altitude. Of the 801 cases, 749 (93.5%) were treated with 2 h GLO. Of those 749 cases treated with 2 h GLO, 728 (97.2%) were asymptomatic at the beginning of the GLO treatment, and 21 (2.8%) resolved during the treatment. Of the 728 cases that were asymptomatic at the beginning of GLO, 718 (98.6%) required no further treatment and 10 subjects had recurrence of symptoms or delayed onset of symptoms. Therefore, of the total 749 DCS cases treated with GLO, 739 (98.7%) were considered successfully treated and 10 (1.3%) were considered unsuccessful. Of the 801 cases of DCS, 48 subjects required HBO therapy; 2.4% of all subject-exposures, and 6.0% of all subjects diagnosed with DCS.

The symptomatology resulting from these exposures has been described in detail elsewhere (8). Briefly, the 801 cases of DCS resulted in 1,119 individual symptoms of DCS. Joint pain represented the vast majority of these symptoms (815, 72.8%) and paresthesia was the second most represented symptom (141, 12.6%). No other individual symptom accounted for more than 4% of the total. Operational diagnostic focus is on the more serious conditions, such as neurologic and respiratory symptoms. These potentially more serious cases were more likely to be treated with HBO. Pain, paresthesia, and skin symptoms were more likely to be treated with GLO. Of the 801 cases of DCS observed, 774 (96.6%) were cases with pain, paresthesia, and/or skin symptoms and 27 (3.4%) were cases with neurologic and/or respiratory symptoms. Of the 774 DCS cases with pain, paresthesia, and/or skin symptoms, 734 were treated with 2 h GLO. Only 9 (1.2%) of these required additional treatment with HBO. Seven of these had pain, paresthesia, and/or skin symptoms recur after GLO and were successfully treated with HBO. Two subjects had neurologic or respiratory symptoms occur after GLO treatment and were successfully treated with HBO. Of the 27 cases of DCS with neurologic and/or respiratory symptoms, 15 were treated with 2 h GLO.
Six of these were described as neurologic, and nine were respiratory symptoms. All 15 were asymptomatic when the chamber reached ground level and no additional treatment beyond the GLO was administered.

The 739 DCS cases successfully treated with 2 h GLO had a total of 907 individual DCS symptoms. A few of these symptoms (33, 3.6%) resolved at exposure altitude before recompression was initiated. The majority of the symptoms (852, 93.9%) resolved during recompression. The median exposure altitude was 8,992 m (29,500 ft), the median altitude of symptom resolution was 5,791 m (19,000 ft), and the mean time ± SEM to resolution was 2 min 17 s ± 6 s. Lastly, 22 (2.4%) of the symptoms resolved at ground level. For those symptoms, the median exposure altitude was 8,687 m (28,500 ft) and the mean time ± SEM to resolution at ground level was 28 min 41 s ± 7 min 57 s.

Of the 749 DCS cases that were treated with 2 h GLO, 136 (18.2%) had no observable VGE while 613 (81.8%) had VGE present. Of the 613 DCS cases with VGE, 353 (57.6%) were categorized as incomplete and not used in subsequent analyses. The reason that these are incomplete is that during the majority of subject exposures, two subjects were in the chamber at one time. If the first subject reported symptoms of DCS and was recompressed to ground level, it was not possible to collect further VGE data on that subject. Complete VGE data are available for 260 (42.2%) of the 613 DCS cases with VGE. Of these, 10 (3.8%) subjects had VGE resolve at altitude before recompression and 69 (26.5%) had VGE resolve either during descent (mean descent time = 6 min 22 s ± 21 s) or at ground level before the first ground level VGE data were obtained (mean time at ground level before VGE data recorded = 6 min 51 s ± 1 min 21 s). In the majority of cases (181, 69.6%), VGE resolved at ground level. The mean time at ground level when the last VGE were observed was 8 min 42 s ± 50 s.

**DISCUSSION**

Analysis of the AFRL database shows that GLO has been 98.7% effective in the treatment of 749 cases of altitude DCS. These data provide validation for the current USAF guidelines for the treatment of altitude DCS.

Briefly, DCS results from evolved inert gas bubbles when subjects are exposed to reduced atmospheric pressure. Historically, this condition was observed in underground workers and divers when they were returning to ground level pressure from being at an increased pressure. Treatment of this type of DCS consists of recompression to an increased pressure and then a slow staged decompression back to ground level. Altitude DCS is unique in that the return to ground level pressure is in itself recompression. In fact, the return from 9,144 m (30,000 ft, 4.3 psi) to ground level produces a greater reduction in gas bubble diameter than U.S. Navy Treatment Tables 5 and 6 (Fig. 2). Therefore, it is not surprising that descent in itself is an effective treatment for altitude DCS. Currently, we are conducting studies comparing the use of GLO and ground level air for DCS cases that resolve on descent. This will determine if GLO is necessary for the prevention of late-onset and recurring altitude DCS symptoms.

Rudge (7) examined the use of GLO in 176 altitude DCS cases. In 49 (27.8%) of these subjects, symptoms failed to resolve with GLO and the subjects were treated with HBO. However, as noted by Rudge, his subject population can be divided into two distinct sub-populations: attendants and trainees during training flights, and research subjects. These sub-populations showed very different DCS symptom onset and resolution characteristics. In the 56 research subjects studied by Rudge, 100% had symptom onset at altitude, 54 were asymptomatic at the beginning of GLO, and only 3 required HBO. These data, and the success rate of GLO of 94.6%, are more consistent with the current findings also studying research subjects. Attendants and trainees during training flights demonstrated different results. In the 120 attendants and trainees during training flights studied by Rudge, only 42 (35%) had symptom onset at altitude, while 78 (65%) had DCS symptoms occur at ground level, and a total of 46 subjects (38.3%) required HBO.

Both attendants and trainees during training flights and research subjects undergo hypobaric exposures under controlled chamber conditions. Why then would the two groups have such markedly different DCS symptom onset and resolution characteristics? One possible explanation lies in the incidence of DCS for the two groups. In the current study, we report a DCS incidence of 40.0%. These altitude exposure profiles were designed to study various aspects of DCS, and therefore, were expected to produce DCS symptoms. In contrast, Baumgartner and Weien (1) report a DCS incidence rate of 0.118% for 239,343 training flight exposures over a 2-yr period. Indeed, training profiles are designed to avoid DCS and it is likely that those subjects experiencing DCS during training exposures are at the extremely DCS-sensitive end of the population. Therefore, it follows that these subjects may have required more aggressive treatment for the DCS symptoms to resolve, and are not indicative of USAF rated aircrew population. The current data, derived from 801 cases of DCS, may more accurately describe the effectiveness of GLO for a research subject population.

As stated above, all hypobaric exposures in our database were terminated as soon as DCS was diagnosed.
Therefore, these results reflect the treatment of the initial symptoms of altitude DCS. The treatment of DCS symptoms that have been allowed to progress is not explored in this paper. The symptoms were subdivided into pain, paresthesia, and/or skin symptoms and neurologic and/or respiratory symptoms. Not all pain, paresthesia, and/or skin symptoms were treated with GLO and not all neurologic and/or respiratory symptoms were treated with HBO. Although the majority (95.6%) of pain, paresthesia, and/or skin symptoms were treated with GLO, if symptoms persisted at ground level, the subject was referred to Hyperbaric Medicine. The final determination of course of treatment was at the discretion of the medical monitor and the Hyperbaric Medicine staff. In 15 DCS cases with neurologic and/or respiratory symptoms in which GLO was used, all symptoms had fully resolved on descent and no further treatment was administered. Therefore, in this limited number of DCS cases with neurologic and/or respiratory symptoms, which had resolved on descent, GLO was 100% effective.

The majority of DCS cases in the AFRL database that were treated with GLO resolved early during recompression. Again, this is most likely due to the endpoints used in the database. Since minor symptoms were not given time at altitude to progress into more intense or serious symptoms, resolution was achieved more rapidly than if symptoms were allowed to progress. VGE, however, did not follow the same pattern. Of the DCS cases treated with GLO, 18.2% did not have detectable VGE. These findings corroborate our previous findings that not all DCS cases are accompanied by VGE (10). In those cases in which complete VGE data were available, 69.6% had VGE present at ground level following the exposure. The length of time that VGE remained at ground level ranged from 1 to 93 min (mean: 8 min 42 s ± 50 s). Given the broad range of VGE resolution time, factors other than simple Boyle’s Law bubble dynamics must be involved. Future work will be required to determine the factors that contribute to VGE resolution with recompression.

CONCLUSIONS

This paper reports the treatment of 749 cases of altitude DCS with 2 h GLO, as recorded in the AFRL DCS database. These cases occurred during 2001 subject exposures to simulated altitude, conducted over a 15-yr period at the Air Force Research Laboratory, Brooks Air Force Base, TX. In this database, GLO has been 98.7% effective in the treatment of the initial symptoms of altitude DCS. These data provide indirect support for the current USAF guidelines for the treatment of altitude DCS. It is emphasized that these data are based on research exposures in which subjects were immediately recompressed once DCS was diagnosed. Operational scenarios in which crewmembers remain at altitude with symptoms might be expected to produce DCS cases that require more aggressive treatment than GLO.

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