Severe Altitude Decompression Sickness – When is it Safe to Go Home if You Live Above 8000 ft?

Hart, BB; Powell-Dunford, NC

Introduction

With the advent of manned balloon flights in 1783, aviators gained their first opportunity to push human physiology in the skies. As technological advances allowed aviation pioneers to push the limits of altitude ever higher, an introduction to the adverse effects of acute atmospheric pressure reduction soon followed. Despite implication of bubbles as an etiologic factor in diving decompression sickness (DCS) as early as the mid 1800's, "mal des aviateurs" remained attributed to hypoxia and cold exposure throughout World War I. By the 1930's, altitude DCS was a commonly observed phenomenon in association with high-altitude balloon and, later, high altitude aircraft flights (Figures 1-3).

By the 1940's, lessons learned from the treatment of caisson workers and divers were being cross-applied to altitude casualty management and recompression therapy for altitude DCS cases was begun. Additionally, a number of prospective altitude chambers studies were underway in an attempt to better characterize the incidence and manifestations of altitude DCS. Analogous to the Navy's experience with diving-induced DCS, this research determined that musculoskeletal complaints were the primary manifestation of altitude DCS (Table 1).

Table 1 – Characteristics of Diving vs. Experimentally Induced Altitude DCS

Manifestation	Diving Induced DCS	Experimental Altitude DCS
Musculoskeletal	88.8%	83.2%
Paresthesia / Spinal Cord	2.2%	10.8%
Collapse / Unconsciousness	0.5%	0.5%
Vertigo / Dizziness	5.3%	-
Dyspnea ("chokes")	1.6%	2.7%
Skin Symptoms	0.3%	2.2%

However, these findings were in seeming contrast to anecdotal experience in operational aviation and flight training environments, where the incidence of severe DCS symptoms was noted to be higher. In particular, reports of neurological and pulmonary symptoms were more frequent in individuals presenting for DCS treatment after exposure to the altitude chamber training environment or operational flights. Table 2 presents an averaged incidence (derived from data contained in the associated references) of altitude DCS manifestations as a consequence of these two classes of altitude exposure.

Table 2 – Characteristics of Training and Operational Altitude DCS

Symptom Manifestation	Aircrew Hypobaric Chamber Training	Operational Flights & Treated Patients
Musculoskeletal	84%	80.6%
Neurological	23%	32.7%
Dyspnea ("chokes")	9.4%	6.6%
Skin Symptoms	5.5%	2.3%

Neurological manifestations of altitude DCS tend to be characterized by headache (42%), visual disturbances (30%), mental confusion (25%), and cerebellar signs (9%); whereas relatively few individuals present with complaints of extremity paresthesia (28%). No particular combinations of neurological symptoms have been identified. In contrast, pulmonary manifestations of altitude DCS, more commonly referred to as "chokes", tend to present as a triad of substernal chest pain, cough and dyspnea. However, other studies have shown that subjects may have only one (59%) or two (39%) of these symptoms, rather than all three (10%). Nevertheless, of the three, substernal chest pain was most constant and almost universally present.

Regardless of severity or underlying cause, the vast majority of altitude DCS symptoms are noted to resolve without residua, spontaneously at altitude (3.9%), during descent (84.3%) or soon after returning to ground level (6.9%). Those individuals who did not experience spontaneous resolution of symptoms tended to have more serious manifestations of DSC. Even then, if appropriately treated with normobaric or hyperbaric oxygen therapy, less than 3% of individuals with symptoms persisting after return to ground level atmospheric pressure go on to suffer permanent DCS-related sequelae.

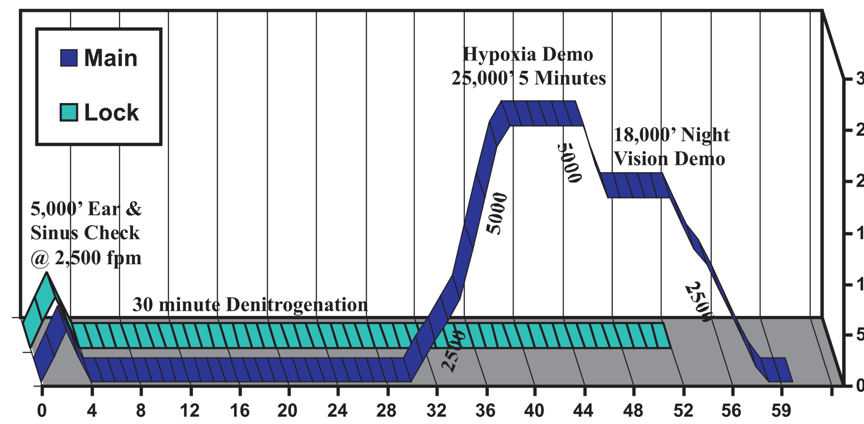
Thus, the successful treatment of patients presenting with altitude DCS is generally not a clinical challenge. What can be more difficult, however, is the implementation of an evidenced-based strategy for returning DCS-injured aviators to duty. We present a patient whose successful treatment for altitude DCS was subsequently complicated by the need for early, sustained re-exposure to altitude.

Case Presentation

The case involves a 41-year-old active duty US Army Medic, specialized in the helicopter evacuation of combat-injured soldiers. Although an experienced aircrew member, at the time of presentation, the patient was temporarily assigned to Ft. Rucker, AL, where he was participating in periodic altitude physiology refresher training. One of the primary goals of this required refresher training is to ensure that pilots and aircrew remain individually aware of their early warning signs of altitude-induced hypoxia. The controlled altitude exposures attainable in the Ft. Rucker hypobaric chamber greatly facilitate this educational process (Figure 4).

The "flight profile" used at Ft. Rucker consists of a low level ascent to 5,000 ft to establish the ability of chamber occupants to equalize their ears and sinuses to rapid pressure changes. Subsequently, occupants breathe 100% oxygen for 30-minutes. Similar to oxygen breathing during diving decompression, this "denitrogenation" period is designed to help reduce the partial pressure of inert gas in the aviators' tissues and, consequently, reduce the risk that they will develop decompression sickness. Once the planned period of denitrogenation is complete, a vacuum is applied to the chamber and a simulated ascent to 25,000 ft occurs, where over the next five minutes, trainees are allowed to experience symptoms of altitude hypoxia. The chamber then descends to 18,000 ft, where trainees also participate in a four-minute night vision demonstration. Total time above 10,000 feet is approximately 20 minutes. Thereafter, the occupants are returned to ground level and exit the chamber for a period of post-flight observation and continued instruction (Figure 5).

U.S. Army School of Aviation Medicine 25,000 Feet USA Original/Refresher Type IV



Climb the chamber from GL to 5,000' by 5,000' fpm.
Descend the chamber from 5,000 to GL by 5,000' fpm.
Climb the chamber from GL to 25,000' by 5,000' fpm
Note: inform PTO/CFS and Rec when passing though 18,000'
Descending the chamber from 25,000' to 18000' by 5,000' fpm
Descending the chamber from 18,000' to GL by 2,500 fpm

The patient reported that Type IV chamber flight was uncomplicated until reaching approximately 6,000 ft on return to ground level. At that point he experienced sudden onset of shortness of breath and 3/10 neck pain. By the time he exited the chamber a few minutes later, these symptoms had increased in severity and were associated with 5/10 substernal chest pain and coughing paroxysms with deep inspiration. Subsequently, evaluation by Ft. Rucker Flight Surgeons produced a diagnosis of altitude-induced pulmonary DCS. Despite treatment with surface oxygen, the patient's symptoms persisted and he was referred for recompression treatment at the Naval Operational Medicine Institute (NOMI) in Pensacola, FL. On arrival by ambulance approximately four hours after symptom onset, the patient was still noted to be breathing 100% oxygen via a non-rebreathing facemask. Although his substernal chest pain had decreased to 4/10, he was still short of breath and would cough uncontrollably if he attempted to take a deep breath. On mental status examination he was found to be appropriate, but somewhat slow in responding to questions. He also demonstrated some difficulty with short-term memory. Except for some minor posterior neck muscle tenderness, felt to be secondary to helmet-induced strap muscle strain, the patient's physical examination was unremarkable. Other than shallow respirations, his pulmonary and cardiac exams were without finding of abnormalities. In contrast, his cerebellar function exam was notable for multiple abnormalities, including a positive Romberg's sign, mild upper extremity dysdiadochokinesia and an inability to perform tandem gait. The patient's cranial nerves, motor strength, sensation and reflexes were, however, all intact and symmetric.

Concurring with the previous diagnosis of pulmonary DCS, along with the addition of central neurological impairment, the patient was subsequently treated on a US Navy Treatment Table 6. During initial descent to treatment depth, the patient's substernal chest pain and coughing paroxysms resolved. While breathing oxygen during the first treatment period at 60 feet, the patient was observed to be more alert and responsive to questioning. Coincident with this observation, the patient stated that he felt as if "a fog had lifted" in terms of his ability to recall events and interact with the examiners. By the end of the first oxygen-breathing period, the patient was able to pass "sharpened" Romberg testing (i.e. maintain stance despite tandem feet positioning) and exhibited resolution of his dysdiadochokinesia. Treatment on a non-extended Table 6 was completed without incident and the patient remained free of symptom recurrence and residual neurological abnormalities. This restored state of normalcy persisted throughout his follow up 24-hours later. Still, in coordinating the patient's release from medical care, it was discovered that his normal military duty station was located several hundred miles away in Santa Fe, New Mexico. More significantly, the patient's home was found to be inconveniently located at an altitude of over 8000 ft.

As both Army and Navy regulations prohibit a return to altitude in the acute period following treatment for DCS, this patient's otherwise uncomplicated treatment course had now become a thorny dilemma.

Return To Altitude Evaluation

The US Army Aeromedical Policy Letters, US Air Force Aircrew Waiver Guide, US Navy Aeromedical Reference and Waiver Guide and the US Navy Diving Manual all contain policy statements addressing return to aviation duty after treatment for decompression sickness. The specific guidelines are dependent upon the type of DCS symptoms experienced (i.e. Type I vs. Type II), their severity and the presence or absence of residua. Table 3 summarizes the current policies contained in the four medical references.

Table 3 – US Army, Air Force and Navy Return to Flying Status Policies

DCS Manifestation Class	US Army Aeromedical Policy Letters	US Air Force Aircrew Waiver Guide	US Navy Aeromedical Reference & Waiver Guide	US Navy Diving
Altitude Exposure (history of recent diving, flight or altitude chamber exposure)	24 Hours	24 Hours	24 Hours (may be reduced to 12 hours for urgencies)	Depends on Residual Nitrogen Time calculation and flight / dive altitude planned
Type I DCS Non-Severe Symptoms (i.e. pain only, skin or lymphatic system involvement)	Minimum of 3 days after symptoms have completely resolved	Minimum of 3 days with no evidence of residual effects	Minimum of 3 days with no evidence of residual effects	Minimum of 3 days with no evidence of residual effects for passenger flight / 7 days for diving duty
Type II DCS Severe Symptoms (i.e. neurological, pulmonary and/or vestibular system involvement)	Minimum of 30 days grounding, waiver required before return to flying duty	Minimum of 3 days with no evidence of residual effects	Minimum of 14 days with no evidence of residual effects	Minimum of 3 days with no evidence of residual effects for passenger flight / 14-30 days for diving duty
Recurrent Type I or II Symptoms	Disqualifying without waiver	Generally Tx as a primary case	Disqualifying without waiver	Generally Tx as a primary case
Residual Symptoms	Disqualifying without waiver	Disqualifying without waiver	Disqualifying without waiver	DMO concurrence for passenger flight / disqualifying for dive duty without waiver

In this patient's case, his symptoms and concurrent qualification as a US Army helicopter aircrew member required application of US Army aeromedical policy standards for the initial presentation of Type II DCS. Thus, as readily gleaned from Table 3, US Army standards for Type II DCS normally prohibit a return to altitude exposure for a one-month period after full neurological recovery. Thus, initial plans to return the patient to his home in Santa Fe by return flight were relatively contraindicated, as most commercial aircraft cabins are pressurized to an altitude equivalent of 8,000 feet during flight. Although ground transportation would normally provide a feasible alternative, this option was also obviated given that the patient's return route to New Mexico would traverse mountain ranges in excess of 10.000 feet and, ultimately, result in his sustained exposure to altitude of 8,000 feet. From the practical standpoint, mandating that the patient remain near sea level at Ft. Rucker for a period of 30-days would require his parent command to authorize additional Temporary Duty (TDY) travel and his family to tolerate a month long period of separation. Neither party was particularly receptive to such a proposal, so methods to objectively evaluate the patient's ability to return to altitude were sought.

A review of the available literature and consultation with senior Flight Surgeons in all three services suggested that few, if any, DCS symptoms were known to recur after a one-week symptom free period. Thus, the patient was scheduled to undergo a controlled altitude chamber exposure seven days after completing his successful recompression therapy. While such "baro runs" are usually performed as a means of assessing an individual's ability to tolerate pressure changes (i.e. after previous barotrauma to the ears, sinuses, teeth, and intestines or surgical procedures on the same), in this case, it was the patient's tolerance of moderate tissue hypoxia that was being tested. While directly monitored by a Navy Undersea Medical Officer, a diving qualified nurse and two flight physiologists, the patient was decompressed in the NOMI hypobaric chamber to an altitude equivalent of 10,000 feet. At all times, the patient continued to breathe ambient chamber air. Within minutes, the patient's arterial saturation had decreased to a steady state of 87%. Despite this sustained desaturation, the patient remained alert and oriented to his surroundings, with no noted recurrence of his previous cognitive or pulmonary complaints. A twenty-minute period of observation was begun. This period of time approximates the time that many altitude chamber training flight profiles spend above the 10,000-foot level. At the completion of this period, a formal evaluation of the patient's mental status, cranial nerve, motor, cerebellar and reflex function was conducted. As no patient abnormalities were identified, the hypobaric exposure was extended for another twenty minutes of observation. Once again the patient remained without a recurrence of symptomatic complaints or identification of objective abnormalities on serial neurological testing, . The altitude chamber was then returned to ground level and the patient observed for a one-hour period. As the patient remained symptom free throughout this controlled hypoxia challenge, it was felt that he would be at low risk for the development of recurrent symptoms or adverse neurological sequelae should he return, at the one week point, to his mountain home in Santa Fe, New Mexico.

On follow up with the patient 24-hours after his return to New Mexico, the patient related that his flight had been uneventful and he continued to remain symptom free. This subjective assessment was subsequently confirmed by his parent command's Flight Surgeon, who was unable to identify any residual abnormalities on detailed neurological examination. Additionally, other objective tests, such as a spiral-cut computerized tomography of the patient's chest (looking for evidence of pulmonary barotrauma, blebs, fistulae or vascular malformations) and an echocardiogram (assessing the presence of patent foramen ovale or other right to left intracardiac shunts) were found to be normal. Consequently, the patient was returned to full flight duty status. Thus, despite its relatively brief duration, the patient's controlled, altitude chamber hypoxia challenge appeared to be effective in both predicting his sustained tolerance of altitude exposure and supporting his early return to altitude environments.

Conclusions

Fortunately, prompt treatment with normobaric or hyperbaric oxygen results in rapid, complete resolution of altitude DCS signs and symptoms in the substantial majority of cases. This is true even when the presenting complaints are consistent with serious, Type II DCS involvement of the pulmonary, vestibular or central nervous systems. Nevertheless, in effecting an aviator's ultimate return to flight duty, the relative speed with which such objective recovery can be achieved is offset to some degree by subjective delays imposed by minimum grounding standards. It is proposed that, in a manner analogous to pressure tolerance testing, controlled exposures to altitude chamber hypoxia may provide an objective means for assessing aviator "fitness for duty" subsequent to experiencing altitude DCS and, ultimately, speed their return to active flight status.

References

1. *Early Balloon Flight in Europe, United States Centenial of Flight Commission.*
2. Fryer, D.I., *Subatmospheric decompresson sickness in man. AGARD.* 1969, New York: Pelham.
3. Davis, J.C., et al., *Altitude decompression sickness: hyperbaric therapy results in 145 cases.* Aviat Space Environ Med, 1977. 48(8): p. 722-30.
4. Ryles, M.T. and A.A. Pilmanis, *The initial signs and symptoms of altitude decompression sickness.* Aviat Space Environ Med, 1996. 67(10): p. 983-9.
5. Keays, F.L., *Compressed air illness, with a report of 3692 cases.* Pub Cornell Univ Med Col, 1909. 2: p. 1-55.
6. Wirjosemito, S.A., J.E. Touhey, and W.T. Workman, *Type II altitude decompression sickness (DCS): U.S. Air Force experience with 133 cases.* Aviat Space Environ Med, 1989. 60(3): p. 256-62.
7. Balldin, U.I., A.A. Pilmanis, and J.T. Webb, *Pulmonary decompression sickness at altitude: early symptoms and circulating gas emboli.* Aviat Space Environ Med, 2002. 73(10): p. 996-9.
8. Rudge, F.W., *Variations in the presentation of altitude-induced chokes.* Aviat Space Environ Med, 1995. 66(12): p. 1185-7.
9. Muhm, J.M., et al., *Effect of aircraft-cabin altitude on passenger discomfort.* N Engl J Med, 2007. 357(1): p. 18-27..

DEPARTMENT OF THE NAVY · UNITED STATES OF AMERICA

NAVAL OPERATIONAL MEDICINE INSTITUTE · PENSACOLA, FLORIDA