Decompression Sickness; Not Only in Divers: Altitude as a Risk Factor

Oded Ben-Ari MD MHA[1,2,3], Daniel Gabbai MD[2], and Idan Nakdimon MSc[2]

[1]Department of Military Medicine and "Tzameret", Faculty of Medicine, Hebrew University of Jerusalem, Jerusalem, Israel
[2]Department of Aviation Physiology, Israeli Air Force Aeromedical Center, Ramat Gan, Israel
[3]Adelson School of Medicine, Ariel University, Ariel, Israel

ABSTRACT **Background:** Decompression sickness (DCS) is a clinical syndrome caused by a substantial reduction in barometric pressure. DCS is more common among divers but may also occur during flight or altitude chamber (hypobaric chamber) training. DCS is classified according to symptoms as either Type 1 (musculoskeletal and skin involvement) or Type 2 (neurological and pulmonary involvement). DCS may be life threatening and often necessitates treatment with hyperbaric oxygen therapy (HBOT).

Objectives: To examine the risk for altitude decompression sickness (ADCS) in altitude chamber training and to compare ADCS symptoms and treatment to those of DCS in divers (DDCS).

Methods: We conducted a retrospective cohort study that included all cases of ADCS in the Israeli Air Force between 2015 to 2022. We collected demographic, flight platform, altitude chamber training, clinical manifestations, and treatment data. Data regarding DDCS was obtained via a literature review.

Results: There were 2279 altitude chamber trainees and aviation physiology instructors. Of these, 11 presented ADCS, leading to a calculated ADCS risk of 0.5%. An additional four cases were reported following combat flights. Musculoskeletal involvement was the most common symptom in both DDCS and ADCS. A shorter HBOT protocol was used in 53% of the ADCS cases but only in 30% of the DDCS cases.

Conclusions: Overall, ADCS is a rare event, occurring in less than 1% of altitude chamber trainees. The common manifestation is of musculoskeletal involvement, and the mainstay of treatment remains HBOT.

IMAJ 2026; 28: 352–356

KEY WORDS: aircrew, altitude chamber, aviation, decompression sickness (DCS), hyperbaric oxygen therapy (HBOT)

Decompression sickness (DCS) is a clinical syndrome that is usually caused by a change in the barometric pressure, from high pressure to low pressure. As a result of a reduction in environmental pressure, extravascular and intravascular dissolved gas bubbles are formed. These gas bubbles occlude blood vessels and impair tissue functions [1]. Overall, DCS is a rare phenomenon. Its occurrence is more common among divers; however, aircrew members are also at risk of DCS. Altitude decompression sickness (ADCS) is a subtype of DCS and may occur in three mechanisms: flights at high cabin altitude, sudden loss of cabin pressure, and altitude chamber training [2-4]. Altitude chamber training is the most common cause of ADCS [2]. Several risk factors have been described in the literature with regard to ADCS, either flight related or personal related factors. High or long cabin altitude flights and rapid rate of ascent are examples of flight-related factors. Being overweight, older age, dehydration, and alcohol consumption are among the personal related risk factors [5]. The risk for DCS may be mitigated by breathing 100% oxygen before an expected pressure decline (known as denitrogenation) [6].

DCS can be manifested by a wide variety of signs and symptoms, which divide DCS into two types. Type 1 DCS is a mild illness, which usually presents with joint pain, pruritic rash, occasionally lymph node enlargement, and constitutional or nonspecific manifestations such as dizziness, fatigue, headache, and malaise. Type 2 DCS is a severe and can be a life-threatening condition involving the nervous, cardiovascular, and respiratory systems [7]. Reinstituting pressure is the basis for DCS treatment. Therefore, the therapeutic standard for DCS treatment is hyperbaric oxygen therapy (HBOT). Some of the mild DCS cases may be treated with oxygen only. The United States Air Force policy is to ground aircrew from flight for 72 hours following an ADCS incident [5].

The aim of this study was to examine the risk for ADCS in altitude chamber training and also to compare altitude chamber training and flight ADCS symptoms and treatment to those of DCS in divers (DDCS).

PATIENTS AND METHODS

This retrospective cohort study included all cases of ADCS in the Israeli Air Force (IAF) between 2015 and 2022 from both altitude chamber trainings and combat flights.

All cases that were suspected of ADCS in the IAF between January 2015 and December 2022 were included in the study. ADCS was identified according to relevant symptoms [7]. Demographics, platform, clinical manifestations, and treatment data were collected. For altitude chamber ADCS risk calculation, we excluded ADCS cases that occurred while flying.

All individuals who participated in the altitude chamber training sessions were deemed medically capable for all flight duties by the Israeli Aeromedical Center, and specifically for training in the altitude chamber.

The IAF altitude chamber capacity is 11 trainees; however, in an average training only 6 trainees occupied the chamber. The IAF training protocol for altitude chamber training includes an ascent to a maximal altitude of 7620 meters (25,000 feet). The ascent and descent rates are 1524 meters/minute (5000 feet/minute). Preceding the training, a 30–45 minute pre-oxygenation period (denitrogenation) of breathing 100% oxygen is required [8].

For comparison of ADCS to DDCS, data regarding DDCS were obtained through a literature review. MEDLINE was searched using PubMed for meta-analyses and review articles. The search was limited to articles published in English for which an abstract was available, with the term *decompression sickness* appearing in the title. An additional search using similar characteristics, but with the search terms *hyperbaric oxygen treatment* and *decompression sickness*, was performed to obtain data regarding HBOT. As no publicly available patient-level datasets exist that allow direct comparisons with the present ADCS case series, symptoms distribution and treatment modalities for DDCS were extracted from aggregated data presented in the identified review articles.

Graphs and comparisons of symptom distributions and treatment types were conducted using Microsoft Excel™ 2016 Version 16.23 for Mac (Microsoft® Corporation, Redmond, WA, USA)

Ethics approval for this study was granted by the Israeli Defense Forces Institutional Review Board.

RESULTS

During the study period, 272 altitude chamber training sessions were performed in the IAF. Of 2279 trainees and aviation physiology instructors, 11 cases of ADCS were reported, with a calculated risk of 0.5%. An additional four cases of ADCS occurred during combat flights. These in-flight cases were associated with in-flight pressurization system failures, resulting in unplanned cabin altitude increases. No pre-breathing of 100% oxygen was performed prior to any of these flights. Two events occurred in F-16 aircraft, one in an F-15, and one in an M-346 aircraft. Demographics, flight characteristics, and ADCS type of these 15 ADCS cases are presented in Table 1. Mean age was 24.9 ± 6.8 years (range 19–42 years). Detailed demographic data are presented in Table 2.

Table 1. Patient demographics for ADCS

Variable	Value
Total number of patients	15
Altitude chamber	11 (73%)
risk	0.5%
Flight	4 (27%)
Age in years (mean ± SD)	24.9 ± 6.8
Sex (female:male)	4:11 (27%:73%)
Maximal altitude (km [kft], mean ± SD)	7.8 ± 1.2 [25.7 ± 3.9]
During altitude chamber	7.6 ± 0.0 [25.0 ± 0.0]
During flight	8.5 ± 2.2 [27.8 ± 7.2]
Treatment	
HBOT type (USNTT5:USNTT6)	7:6 (47%:40%)
100% oxygen	1 (7%)
No treatment	1 (7%)

ADCS = altitude decompression sickness, HBOT = hyperbaric oxygen therapy, SD = standard deviation, USNTT = United States Navy Treatment Table

In our literature review, we found six meta-analyses, but none had any relevance to the study goal. There were 35 review articles on the subject; however, only one with a symptoms distribution analysis [9]. A single meta-analysis and 99 review articles regarding DCS treatment were found. Only one review article was found to be relevant, and it contained information regarding specific hyperbaric treatments [10].

Table 3 describes symptom distribution in DDCS based on the review by Mitchell and colleagues [9] and

Table 2: Distribution of Israeli Air Force ADCS cases

Case #	Age in years	Sex	Profession	Platform	Altitude km (kft)	Symptoms	Symptom classification	Treatment	HBOT tail treatment
1	20	Male	Cadet pilot	AC	7.6 (25)	Bilateral knee, low back and shoulders numbness and pain; extreme fatigue	Musculoskeletal, spinal cord, constitutional	USNTT5	1
2	34	Male	Flight engineer	AC	7.6 (25)	Radial nerve area numbness	Spinal cord	USNTT5	No
3	21	Male	API	AC	7.6 (25)	Left shoulder pain	Musculoskeletal	USNTT6	1
4	25	Male	Aircrew	AC	7.6 (25)	Left elbow pain	Musculoskeletal	USNTT5	No
5	26	Female	API	AC	7.6 (25)	Right shoulder pain, arm numbness	Musculoskeletal, spinal cord	USNTT5	1
6	20	Male	Tactical crew	AC	7.6 (25)	Right shoulder pain	Musculoskeletal	USNTT5	No
7	37	Male	Aircrew	Combat flight	12.2 (40)	Extreme fatigue	Constitutional	–	–
8	24	Male	Aircrew	Combat flight	7.9 (26)	Dizziness, Nausea	Constitutional	USNTT6	No
9	22	Male	Cadet pilot	AC	7.6 (25)	Right shoulder and arm pain	Musculoskeletal	100% O_2	–
10	19	Male	Cadet pilot	AC	7.6 (25)	Bilateral groin pain	Spinal cord	USNTT6	1
11	20	Female	Cadet pilot	AC	7.6 (25)	Slow movement, weakness, hand numbness	Brain, spinal cord	USNTT5	2
12	21	Female	API	AC	7.6 (25)	Elbow and shoulder pain, extreme fatigue, headache	Musculoskeletal, constitutional	USNTT6	3
13	42	Male	Aircrew	Combat flight	6.7 (22)	Headache	Constitutional	USNTT6	No
14	21	Male	Aircrew	Combat flight	7.0 (23)	Joint pain in the extremities	Musculoskeletal	USNTT6	No
15	21	Female	API	AC	7.6 (25)	Left shoulder pain	Musculoskeletal	USNTT5	1

AC = altitude chamber, ADCS = altitude decompression sickness, API = aviation physiology instructor, DCS = decompression sickness, HBOT = hyperbaric oxygen therapy, USNTT = United States Navy Treatment Table

ADCS symptom distribution from the IAF cases. In both datasets, the majority of symptoms were predominantly classified as DCS Type 1, with musculoskeletal involvement appearing in approximately 60% of cases. Cutaneous symptoms were described in up to 50% of cases among divers but were not seen in the ADCS cases. In half of our ADCS cases, symptoms appeared immediately or shortly after pressure drop. However, in one case, symptoms appearance was documented as late as 16 hours following pressure drop.

The standard treatment for DCS is HBOT. DCS cases are generally treated using the U.S. Navy Treatment Tables (USNTT) 5 and 6. Both protocols are similar in the depth parameter of 2.8 atm but differ in exposure time. The profile of USNTT5 lasts 2 hours and 15 minutes, while USNTT 6 continues for 4 hours and 45 minutes [11,12]. Of our 15 participants with ADCS, 1 was not treated and 1 was treated with 100% oxygen. The remaining 13 (87%) were treated with HBOT [Table 1]. Of these 13 participants who were treated with HBOT, 7 needed more than one HBOT treatment (tail treatment). Antonelli and colleagues reported that approximately 70% of DDCS cases were treated using USNTT6, whereas the HBOT treatment of our ADCS cases was divided almost equally between USNTT5 and USNTT6, 53% and 47%, respectively [10].

Table 3. DCS symptoms: Mitchell's et al. review (2022) vs. IAF ADCS

Symptom	DDCS (Mitchell et al. 2022)	IAF ADCS
Musculoskeletal	50–65%	60%
Spinal cord (including motor weakness and numbness)	20–30%	33%
Constitutional (including fatigue, dizziness and headache)	20–40%	33%
Brain (including cognitive impairment, visual field changes, ataxia and focal weakness)	5–10%	7%
Inner ear (including vertigo, hearing loss and tinnitus)	10–20%	0%
Cutaneous	40–50%	0%
Lymphatic	1–5%	0%
Cardiopulmonary (including cough, chest pain and dyspnea)	1–5%	0%
Cardiovascular	< 1%	0%

ADCS = altitude decompression sickness, DCS = decompression sickness, DDCS = diving decompression sickness

DISCUSSION

DCS is commonly associated with diving but can also occur during flight and altitude chamber training. From a physiological point of view, Haldane's model was historically used to estimate the risk for developing DCS. According to this model, the threshold for DCS development was defined as a decline of 50% in atmospheric pressure. During flight or altitude chamber training, such a decline occurs when the cabin altitude exceeds 5486 meters (18,000 feet) [3]. Over time, additional and more accurate models (Critical supersaturation, ADRAC) were proposed for estimating DCS risk development [5].

Altitude decompression sickness tends to be a rare event both during flight and altitude chamber training sessions. In our study, the calculated risk for ADCS event during altitude chamber training was 0.5%. This is a relatively high risk compared to other facilities in the world [13]. DCS diagnosis may be challenging and sometimes relies on clinical impression and experience. The IAF practices a high index of suspicion for ADCS events, which may explain the higher risk found in this study.

Musculoskeletal symptoms were the most common manifestation of both DDCS and ADCS. These symptoms are classified as DCS Type 1, which is known to be more common than DCS Type 2.

The majority of DDCS cases are treated in a hyperbaric chamber using the USNTT6, while only 30% are treated using the USNTT5 [10]. The latter is reserved for mild DCS cases. As the IAF practices a high index of suspicion with regard to ADCS, even very mild cases, which otherwise would have been treated with 100% oxygen breathing or observation, are often treated with HBOT, using the shorter protocol of USNTT5. Therefore, it is not surprising that USNTT5 was used in 53% of our HBOT.

During study period, there were only four cases of flight ADCS. Flight hours in the IAF far exceeds those of altitude chamber training. Hence, the risk for ADCS during flight is much lower than that of ADCS during altitude chamber training. The standard altitude chamber training protocol involves an ascent to 7620 meters (25,000 feet), whereas normal cabin altitude in pressurized aircraft rarely exceeds 5486 meters (18,000 feet), which is the cutoff value for ADCS. Importantly, all in-flight ADCS cases occurred in the setting of unplanned pressurization system failure, rather than during routine, normally pressurized flight operations.

Measures can be taken to mitigate the risk for ADCS: Reducing rate of ascent and extending pre-oxygenation time can be implemented to improve altitude chamber training safety [14]. Flight duration at cabin altitude exceeding 5486 meters (18,000 feet) should be reduced to the minimal necessary level during both training and operational flights. Emergency procedure manuals should be standardized to include a descent below 5486 meters (18,000 feet) in the event of pressurization system failure (rather than 7620 meters [25,000 feet]). A pressurization system failure light indicator, which is lacking in some F-15 aircraft, should be installed in all platforms.

This study has several limitations. Most notably, the comparison between ADCS cases and DDCS is based on aggregated data derived from published review articles rather than from primary patient-level datasets. Therefore, the comparisons presented should be interpreted as descriptive rather than as definitive quantitative. In addition, the sample size was small, and the study period was relatively short. Altitude chamber protocols were not identical for all trainees, as two main protocols, which slightly differ from one another (ascent rate, pre-oxygenation period), were used for different trainee populations.

CONCLUSIONS

DCS is a potential risk in diving, and it also poses a threat for aircrew. Overall, ADCS is a rare event, occurring in less than 1% of altitude chamber trainees. In this study,

we found that the common manifestation is of musculoskeletal involvement (Type 1 DCS), and the use of the USNTT5 was more common for ADCS than it was for DCS in our cohort. Although uncommon, ADCS may also occur during operational flights, particularly in the setting of pressurization system failure.

Correspondence

Mr. I. Nakdimon
Department of Aviation Physiology, Israeli Air Force Aeromedical Center, Ramat Gan 5262000, Israel
Fax: (972-3) 737-6784
Email: nadidim@gmail.com

References

1. Schmitz G. Case report: Biphasic autonomic response in decompression sickness: HRV and sinoatrial findings. *Front Physiol* 2025;16:1605779.
2. Brandt MS, Morrison TO, Butler WP. Decompression sickness rates for chamber personnel: case series from one facility. *Aviat Space Environ Med* 2009; 80 (6): 570-3.
3. Harrison MF, Butler WP, Murad MH, Toups GN. Decompression sickness risk assessment and awareness in general aviation. *Aerosp Med Hum Perform* 2021; 92 (3): 138-45.
4. Pollock NW, Buteau D. Updates in decompression illness [Review]. *Emerg Med Clin North Am* 2017; 35 (2): 301-19.
5. Stepanek J, Webb JT. Physiology of decompression stress. In: Davis JR, Johnson R, Stepanek J, Fogerty JA, eds. Fundamentals of Aerospace Medicine. 4th edn. Philadelphia: Wolters Kluwer/Lippincott Williams & Wilkins, 2008: 63-4.
6. Eiken O, Elia A, Gottschalk F, Gennser M, Ånell R. Decompression strain in parachute jumpmasters during simulated high-altitude missions: a special reference to preoxygenation strategies. *Eur J Appl Physiol* 2023; 123 (8): 1637-44.
7. Howle LE, Weber PW, Hada EA, Vann RD, Denoble PJ. The probability and severity of decompression sickness. *PloS One* 2017; 12 (3): e0172665.
8. Nakdimon I, Ben-Ari O, Eliyahu U, Gordon B. Gender differences in tolerance to hypoxia. *J Isr Mil Med* 2021; 18 (51): 23-7.
9. Mitchell SJ, Bennett MH, Moon RE. Decompression sickness and arterial gas embolism [Review]. *N Engl J Med* 2022; 386 (13): 1254-64.
10. Antonelli C, Franchi, F, Della Marta ME, et al. guiding principles in choosing a therapeutic table for DCI hyperbaric therapy [Review]. *Minerva Anestesiol* 2009; 75 (3): 151-61.
11. Mrakic-Sposta S, Brizzolari A, Vezzoli A, et al. Decompression illness after technical diving session in Mediterranean Sea: oxidative stress, inflammation, and HBO therapy. *Int J Mol Sci* 2024; 25 (21): 11367.
12. Kutz CJ, Kirby IJ, Grover IR, Tanaka HL. Aviation decompression sickness in aerospace and hyperbaric medicine. *Aerosp Med Hum Perform* 2023; 94 (1): 11-17.
13. Nakdimon I, Ben-Ari O. Mitigating risks of altitude chamber training [Review]. *Aerosp Med Hum Perform* 2022; 93 (11): 811-15.
14. Rice GM, Vacchiano CA, Moore JL Jr, Anderson DW. Incidence of decompression sickness in hypoxia training with and without 30-min O2 prebreathe. *Aviat Space Environ Med* 2003; 74 (1): 56-61.

Capsule

Mapping B cells in the appendix

B cells within gut-associated lymphoid tissue (GALT) must balance homeostatic control while being constantly exposed to antigens sampled from the gut lumen. To determine how B cells contribute to immune homeostasis in GALT, **Pitcher** and colleagues performed a multiomic analysis of appendix tissue derived from healthy individuals and patients with ulcerative colitis. The spatial organization of immunomodulatory B cell subsets identified within normal GALT microarchitecture was altered in ulcerative colitis, resulting in modified cellular interactions and perturbation of certain B cell-expressed regulatory markers. This loss of B cell subset organization may contribute to the dysregulated immune response in ulcerative colitis.

Sci Immunol 2026; 11 (120): eady8948
Eitan Israeli

Capsule

A better tracker of cancer

The incidence of human papillomavirus (HPV)-associated head and neck cancer is increasing. It is often treated with surgery and sometimes adjuvant therapy, but clear biomarkers for prognostic accuracy are lacking. **Hirayama** et al. evaluated the use of circulating tumor HPV DNA as an indication of disease burden and thus therapeutic treatment. In a prospective patient cohort comparison with droplet digital PCR assays, they showed that their HPVDeepSeek analysis could more accurately determine patients whose cancer would recur up to 17.5 months earlier. This whole-genome sequencing technique could help stratify patient postoperative risk and could potentially be used to identify patients who would benefit from adjuvant therapy.

Sci Immunol 2026; 11 (120): eaec1724
Eitan Israeli