

Australian Defence Force hypobaric chamber training, 1984–2001

Wing Commander Tracy L Smart, BM BS, DipAvMed and
Dr Gordon G Cable, MB BS, ACCAM, DipAvMed, MRAeS

IN FEBRUARY 2001, COMCARE Australia, the Commonwealth Government occupational health and safety authority, served a prohibition notice to the Chief of Defence Force prohibiting hypobaric chamber training in the Australian Defence Force (ADF), effectively bringing to an end over 60 years of hypobaric training of ADF aircrew. The prohibition notice resulted from a number of cases of decompression illness among trainees and instructors. The COMCARE prohibition had the potential to remove the ability of the ADF to conduct training in the signs and symptoms of hypoxia. This decision was the final link in a long and complex chain of events dating back a decade, which included a relocation of the Institute of Aviation Medicine (AVMED) from RAAF Point Cook, Victoria, to RAAF Edinburgh, South Australia, two clusters of decompression illness, a perception that the incidence of decompression illness arising from ADF chambers was inexplicably high, and several attempts to modify training to make it safer.

This article examines the history of hypobaric chamber training in the ADF from 1984 to 2001, the incidence of decompression illness during that period, and the strategies implemented over many years in an attempt to make hypoxia training safer, culminating in AVMED's response to the COMCARE prohibition.

Abstract

- ◆ **Objective:** To examine the history of hypobaric chamber training in the ADF from 1984 to 2001, the incidence of decompression illness during that period, and the strategies implemented in an attempt to develop safer hypoxia training techniques.
- ◆ **Method:** Retrospective review of decompression illness cases and documents pertaining to hypobaric chamber training. Cases were categorised by diagnosis (type 1 or type 2), and by diagnostic certainty (definite, probable, possible).
- ◆ **Results:** In the period studied, decompression illness was considered as a diagnosis in 86 students, comprising 57 definite (66.3%), 11 probable (12.8%), and 18 possible cases (20.9%). The overall incidence of definite or probable decompression illness resulting from training in the chamber of the RAAF Institute of Aviation Medicine was 3.9 cases per 1000 exposures (or 0.39%). Two apparent clusters of decompression illness occurred, in 1995 and 1999. Sixteen reviews or investigations were undertaken by various agencies, and several changes were implemented to improve the safety of training and patient management. A possible consequence of these changes could have been the increased presentation of aircrew with symptoms, and increased diagnosis, referral, and treatment of decompression illness.
- ◆ **Conclusion:** Despite increasing safety procedures, the incidence of decompression illness from ADF chamber training was higher than that reported in the literature by other training organisations. Whether these benefits of hypoxia training outweigh the risks of training is yet to be determined.

ADF Health 2004; 5: 3-10



Wing Commander Tracy L Smart entered the RAAF in 1985. She has completed overseas postings with both the Royal Air Force and the United States Air Force and has been deployed with the ADF to Rwanda, Malaysia, East Timor and the Middle East. She is currently serving her second term as Commanding Officer of the Royal Australian Air Force Institute of Aviation Medicine.



Dr Gordon Cable has worked at the Institute of Aviation Medicine since 1996. He provides training for flight nurses through the University of South Australia and to doctors through Griffith University. Dr Cable is President of the Australasian Society of Aerospace Medicine and edited the Society's journal, *Avmedia*, for 5 years. He is a member of the Royal Aeronautical Society, an Associate Fellow of the Aerospace Medical Association, and is an Australian Designated Aviation Medical Examiner for aircrew. From 1997 to 1999 he served on the council of the Royal Flying Doctor Service (Central Section). He is also a private pilot.

Royal Australian Air Force Institute of Aviation Medicine, RAAF Base Edinburgh, SA.

Tracy L Smart, BM BS, DipAvMed, Commanding Officer; **Gordon G Cable**, MB BS, ACCAM, DipAvMed, MRAeS, Aviation Medical Officer.
Correspondence: Wing Commander Tracy L Smart, Royal Australian Air Force Institute of Aviation Medicine, RAAF Base Edinburgh, SA 5111.
Tracy.Smart1@defence.gov.au

Background

Hypobaric chamber training at a simulated altitude of 25 000 feet (7620 m) has been a fundamental component of aviation training in most air forces since World War II. This training is considered essential and is based on the belief that hypoxia is "the most serious single physiological hazard during flight at altitude".¹ Studies examining the occurrence of inflight hypoxic incidents show that they are reasonably common and often insidious in onset, even with technologically advanced pressurisation systems and breathing apparatus.² Aircrew who have received hypoxia familiarisation training are more likely to recognise and respond to the symptoms of hypoxia than untrained passengers.³ US National Transportation Safety Board (NTSB) statistics reveal a high incidence of hypoxia-

related fatalities in civilian aircrew who do not undergo military style hypoxia training.³ When hypoxia occurs in aircraft, the results can be catastrophic, particularly for the untrained.

Hypoxia familiarisation training is considered a crucial element in military flight safety. Today most NATO countries provide hypobaric chamber training to aircrew using a variety of training flight profiles, but exposure to a rapid decompression and hypoxia experience at a simulated altitude of 25 000 feet remains common.⁴ As a member of the Air Standardisation Coordinating Committee (ASCC), Australia is obliged to provide hypoxia training to its aircrew to ensure interoperability with the US, Canada, the United Kingdom and New Zealand.⁵

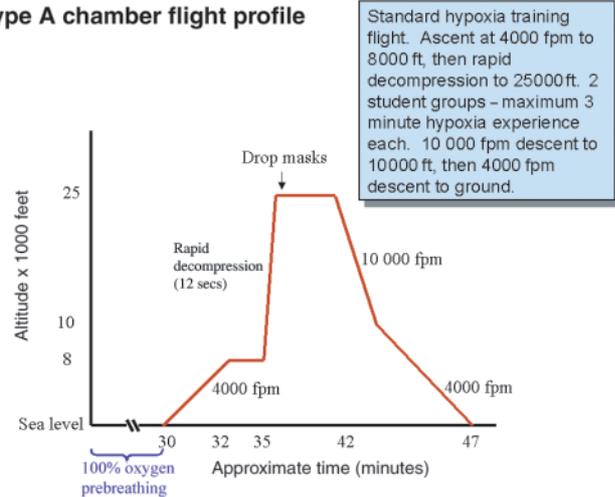
Before 2001, ADF aircrew were required to undertake hypobaric chamber training consisting of three types of flight profiles: the type A chamber flight, which is the standard hypoxia training profile to a simulated altitude of 25 000 feet (7620 m); the type B chamber flight, a night vision training profile to 15 000 feet (4570m); and the type C chamber flight, the pressure breathing profile to 45 000 feet (13 710 m)(Box 1). All ADF aircrew undertook both type A and B chamber flights during their initial AVMED course, and subsequently every 3 years during refresher training. Fast-jet aircrew also experienced a type C chamber flight on conversion to fighter aircraft and on each physiology refresher course. These chamber flights were conducted on consecutive days. Other personnel who underwent training at least once in their careers included medical officers, nursing officers, air traffic controllers and life support fitters. In fact, anyone who was interested in aviation medicine could undertake a one-day introductory course which included a type A chamber flight. This training was conducted at a number of hypobaric training facilities, including RAAF Bases Richmond, Pearce, Edinburgh, Amberley and Point Cook.

Hypobaric chamber training has some attendant risks. A rapid change in ambient pressure not only has the desired effect of reducing oxygen partial pressure, but also the unwanted problems of barotrauma and decompression illness. While not as common as barotrauma, it is decompression illness which causes much concern for hypobaric chamber training centres worldwide, and has resulted in the most recent developments in hypoxia training in the ADF.

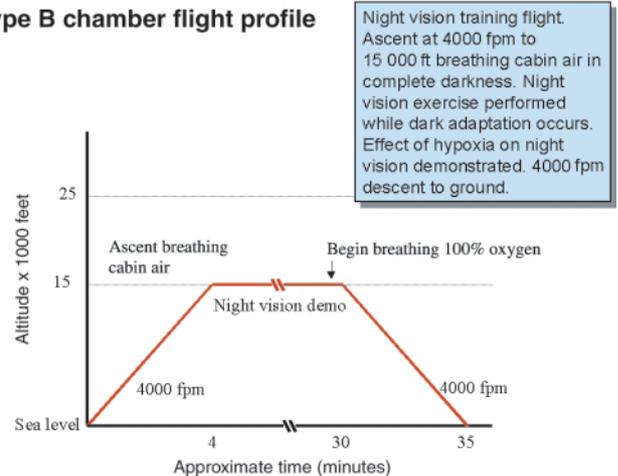
In simple terms, decompression illness is a disorder of evolved nitrogen in body tissues and blood. A rapid decrease in the ambient partial pressure of nitrogen at altitude, well below the partial pressure that exists in the tissues, results in the tissues being "supersaturated" with nitrogen, which predisposes to the formation of bubbles. These bubbles can obstruct vessels, compress structures, and fragment tissues. Intravascular embolic bubbles cause tissue ischaemia and damage to the endothelium, which results in sludging, further hypoxic damage to tissues and loss of intravascular volume. The activation of inflammatory mediators and cells is thought to result in the diverse collection of signs and symptoms known as decompression illness. Signs and symptoms may range from simple joint pains or skin rashes, to respiratory effects, cardiovascular effects and serious neurological disturbances.

I: Standard chamber flight profiles used for hypoxia familiarisation training of ADF air crew before 2001

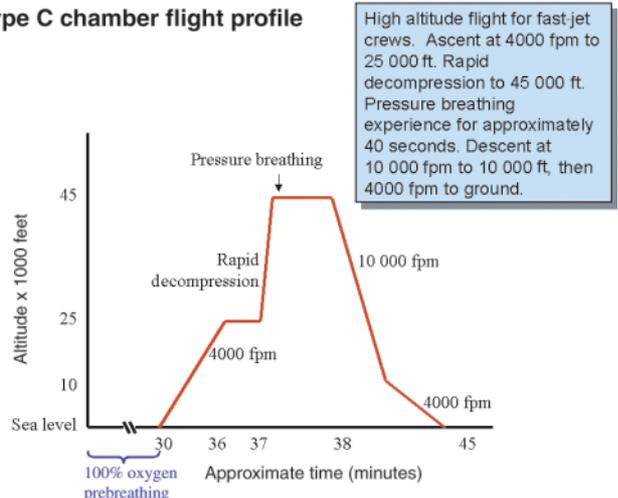
Type A chamber flight profile



Type B chamber flight profile



Type C chamber flight profile



The unpredictable nature of the disorder and its potential to cause life-threatening illness and/or long term sequelae are major concerns. More than 17 000 cases of altitude decompression illness from operations and training before 1959 have been described in the scientific and military literature. Of these, 743 cases were reported as serious, including at least 17 fatalities.⁶ Today, fatalities from altitude exposure are rare, although occasional case reports do exist – the most recent being a fatal case of respiratory decompression illness on a United States Air Force (USAF) operational flight at 28 000 feet (8530 m) in 1988.⁷

The incidence of decompression illness resulting from hypobaric chamber training has been reported by a number of military training organisations. A review of 10 of these reports reveals a range of incidence in various populations from 0.3 to 2.9 cases per 1000 exposures, with a mean incidence of 1 case per 1000 exposures (or 0.1%).⁸⁻¹⁷

Risk factors for decompression illness are well recognised. Increasing altitude above 18 000 feet (5490 m) rapidly increases the risk of decompression illness.^{8-10,14,18} There are case reports of decompression illness occurring at seemingly low altitudes, even as low as 11 000 feet (3350 m).¹⁹⁻²² Repeated altitude exposures were thought to increase risk, but the literature has been inconclusive, and more recent data may refute this theory.²³ There is an increased risk associated with hyperbaric exposure before altitude exposure, as seen with SCUBA diving before flying.²⁴ There is a trend towards increased decompression illness susceptibility with increasing age,²⁵ obesity, recent injury or illness, alcohol intake, excessively cold ambient temperatures, dehydration, and physical exercise at altitude.²⁶ Rate of ascent²⁷ and hypoxia^{19, 28-31} have also been suggested, but not proven, as risk factors.

Many factors are thought to influence individual susceptibility and may explain why decompression illness has such a variable presentation at such a range of altitudes. It has been suggested that individuals may have their own “threshold” altitude which can be defined based on specific circumstances unique to each person.²⁰

The risk of decompression illness can be mitigated by minimising time at altitude, ensuring trainees are fit for altitude exposure by screening for predisposing factors, and by breathing 100% oxygen before the altitude exposure. Denitrogenation by prebreathing 100% oxygen does not completely remove the risk.³² A recent study demonstrated that those subjects who did not prebreathe with 100% oxygen were 2.5 times more likely to develop decompression illness than those prebreathing 100% oxygen for 30 minutes.¹⁵

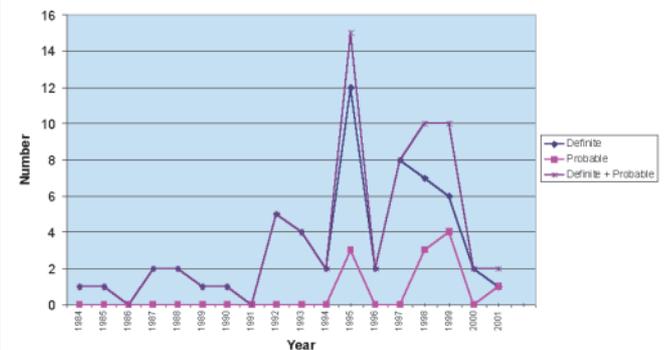
Methods

We retrospectively reviewed all AVMED documents relating to cases of decompression illness and associated administrative procedures between 1984 and 2001. The information sources included, but were not limited to:

- An incomplete electronic database of cases from 1995 to the present

2: Cases of decompression illness during hypoxia training by year

Year	Definite	Probable	Possible	Definite and probable	Total
1984	1	0	0	1	1
1985	1	0	0	1	1
1986	0	0	0	0	0
1987	2	0	0	2	2
1988	2	0	0	2	2
1989	1	0	2	1	3
1990	1	0	0	1	1
1991	0	0	0	0	0
1992	5	0	0	5	5
1993	4	0	0	4	4
1994	2	0	0	2	2
1995	12	3	1	15	16
1996	2	0	0	2	2
1997	8	0	7	8	15
1998	7	3	6	10	16
1999	6	4	0	10	10
2000	2	0	2	2	4
2001	1	1	0	2	2
Total	57	11	18	68	86



Apparent clusters of cases of decompression illness in 1995 and 1999.

- Hypobaric chamber incident reports from all ADF hypobaric chamber facilities
- COMCARE reports
- General correspondence in the form of minutes, letters and emails
- Internal and external reviews and reports
- Central aircrew medical fitness boards for aircrew members who suffered decompression illness
- Chamber logs recording the number of students trained between 1989 and 2000.

A new electronic spreadsheet database was created using Microsoft Excel software. For each case, the following information was recorded: patient demographic details (including name, service number, age, sex, mustering), date of incident, the location of the chamber and the training profile,

the diagnosis, diagnostic category (definite, probable, possible), clinical symptoms, treatment, and outcome if known.

Cases of decompression illness were classified by severity as type 1 or type 2 based on available clinical information.³⁰ Patients with pain only (bends) or skin manifestations (including paraesthesiae and subjective numbness) were classified as type 1. Patients with central nervous system disturbances (including documented alterations of cutaneous sensation on testing), respiratory effects or cardiovascular manifestations were classified as type 2.

Due to the inconsistency and incomplete nature of the available data and the often vague clinical nature of decompression illness, the diagnosis could not always be determined with certainty. Definite cases were defined as those that were referred for hyperbaric oxygen therapy and recompression, or where the case notes specifically stated a diagnosis of decompression illness.

Probable cases were defined as those where the diagnosis was not specified, but the clinical history appeared to indicate decompression illness.

Possible cases were defined as those considered unlikely to be decompression illness, but for which the diagnosis could not be excluded on clinical grounds or from the information available.

Results

Decompression illness data

During hypoxia training from October 1984 to January 2001, the ADF had 86 cases where a diagnosis of decompression illness was entertained: 57 definite cases (66.3%), 11 probable cases (12.8%), and 18 possible cases (20.9%) (Box 2).

4: Person-exposures to altitude by chamber flight profile and year for the AVMED chamber, and incidence of probable and definite decompression illness

	Year	A	B	C	Other	Total	Decompression illness cases	Cases per 1000 exposures
Point Cook	1989	245	88	80	7	420	0	0.0
	1990	525	195	114	5	839	0	0.0
	1991	493	119	124	23	759	0	0.0
	1992	508	129	116	0	753	2	2.7
	1993	429	168	69	0	666	3	4.5
	1994	411	195	34	2	642	2	3.1
Edinburgh	1995	670	496	91	0	1257	10	8.0
	1996	714	529	88	0	1331	2	1.5
	1997	667	532	56	0	1255	6	4.8
	1998	577	441	54	0	1072	4	3.7
	1999	540	471	35	6	1052	9	8.6
	2000	326	285	42	96	749	2	2.7
	2001	24	23	9	0	56	2	35.7
Total	6129	3671	912	139	10851	42	3.9	

3: Distribution of decompression illness cases by chamber location

Year	AVMED	Edinburgh	Pearce	Richmond
1984	1			
1985	1			
1986				
1987	1			1
1988	2			
1989			1	
1990			1	
1991				
1992	2	1		2
1993	3			1
1994	2			
1995	10	4		1
1996	2			
1997	6			2
1998	4		2	4
1999	9			1
2000	2			
2001	2			
Total	47	5	4	12

Excluding the "possible" cases (defined as unlikely to be decompression illness) there were 68 cases of decompression illness over the 18-year period, affecting 60 men and 8 women, with an average age of 28 years.

Box 3 shows the distribution of cases across ADF hypobaric chambers for which data were available (no data were obtained for RAAF Amberley). Consistent data relating to the number of chamber exposures were available only from 1989 to 2001, and only for training at AVMED (Box 4). In the 12-year period 1989–2001, there were 10851 person-exposures to altitude at AVMED, with an incidence of decompression illness for the AVMED chamber of 3.9 cases per 1000 exposures, or 0.39%. During the clusters (1995 and 1999) the incidence rate was about double the average incidence.

The severity and treatment of decompression illness cases is summarised in Box 5.

The incidence of decompression illness by chamber flight profile is shown in Box 6. The data show that increasing chamber altitude is associated with an increasing incidence of decompression illness. The "Other" data, which include USAF Type 37 profiles, high altitude parachute opening (HAPO) chamber operations and various research profiles, should be viewed with suspicion due to the relatively small number of subject exposures.

Reviews and changes to hypobaric chamber training

In the 10 years from 1992, 16 reviews or investigations were undertaken by various agencies: 7 were initiated by AVMED, 4 by Health Services personnel, 4 by COMCARE, and 1 by the Defence Safety Management Agency (DSMA). The nature of these reviews varied from the investigation of individual cases of decompression illness (Health Services 1992; AVMED 1995, Jan 2001; COMCARE 1998, 1999) to a complete overview of training (Health Services 1994; AVMED 1995, 1998, Aug 2001).

The trigger for change in hypobaric chamber training was a case of type 2 decompression illness in an RAAF Nursing Officer at the Richmond chamber in 1992, and a subsequent Health Services meeting in July 1994. The first change was to adopt a more aggressive approach to managing suspected decompression illness, including the immediate delivery of 100% oxygen via a tight-fitting aviator's mask, aggressive intravenous fluid therapy, a thorough neurological examination (even for type 1 decompression illness), and discussion of all cases of suspected decompression illness with a hyperbaric specialist and referral to a hyperbaric treatment facility if appropriate. Another major change in management was in the aeromedical disposition of aircrew following decompression illness. In 1995, the Office of the Surgeon General amended ADF Health policy to allow aircrew who had made a full recovery after uncomplicated decompression illness to return to unrestricted military flying after 72 hours. This decision appears to be based on contemporary USAF data and policy of the period.

Significant changes in training procedures also followed the July 1994 meeting, including introduction of denitrogenation of students and instructors by breathing 100% oxygen at ground level before all exposures over 18000 feet. More detailed and thorough briefings before and after chamber training were also undertaken. Before training, students were briefed on necessary diet and exercise restrictions and asked to discuss any medical problems or risk factors they might have with an AVMED medical officer. After the chamber flight, students were asked if they had any specific symptoms, either during the flight or at ground level, and were referred to the treating medical facility if appropriate. They were advised to avoid risk factors such as exercise and alcohol and to seek immediate medical assistance if symptoms occurred.

In 1995, AVMED was relocated from RAAF Point Cook to RAAF Edinburgh. Following an immediate increase in reported cases of decompression illness, further changes to improve safety were implemented. These included changing chamber procedures to minimise the time of exposure to altitudes greater than 18000 feet, instituting a minimum time of 24 hours between chamber flights, cessation of type C chamber flights on refresher courses for some students, establishing a 24-hour AVMED decompression illness consultation service, and more rigorous medical screening of students before training.

There were more cases of decompression illness despite these safety initiatives, prompting a further review by AVMED

5: Severity and treatment of decompression illness cases from all chambers

Year	Diagnosis		Treatment				Residual sequelae
	Type 1	Type 2	Un-certain	Hyper-baric	100% oxygen	Other	
1984		1		1			
1985		1		1			
1986							
1987	1	1		1	1		
1988	2			1	1		
1989	1				1		
1990	1	1		1			
1991							
1992	2	3		5			
1993	2	2		4			
1994	1	1		2			1 numbness left arm
1995	8	5	2	12		3	1 hand tingling
1996	1	1		2			1 visual field defect
1997	5	2		8			1 neurological
1998	5	5		7	2	1	1 memory deficit, depression
1999	10			7	2	1	
2000	2			2			
2001	1	1		1	1		1 memory deficit, depression
Total	42	24	2	55	8	5	6
	(61.7%)	(35.3%)	(3%)	(80.9%)	(11.6%)	(7.3%)	(8.8%)

staff in 1998. Changes implemented then included cessation of type C chamber flights during refresher training for all students, changes in frequency of training from 3 to 5 years (thus reducing the number of individual life time exposures), and cessation of training of personnel with no requirement to fly. A study to validate a new type of chamber flight which combined both type A and B profiles was suggested, however a Health Services review recommended the adoption of USAF profiles for chamber flights instead of this experimental profile. An attempt to evaluate one of these USAF profiles resulted in the then-Chief Instructor developing decompression illness.

Hypobaric chamber training in the ADF first came to COMCARE's attention in 1996 in response to an anonymous phone call from a RAAF aircrew member who was worried about the safety of training. Although initially satisfied with the necessity of training, further investigations of specific cases focused on whether the benefits really outweighed the risks. Following AVMED's decision to cease training pending the outcome of an investigation into two decompression illness incidents in January 2001, a COMCARE Prohibition Notice was issued, prohibiting all AVMED hypobaric chamber training. This was not lifted until the publication of an AVMED report in August 2001 indicating that hypoxia training could be accomplished using alternative means — combined altitude

and depleted oxygen (CADO) — a technique which combines breathing a reduced oxygen gas mixture with exposure to a safe simulated altitude of 10 000 feet.

Discussion

Limitations

There were many limitations in the data available for this study. Incomplete records and poor reporting of incidents in earlier years hampered attempts to identify all cases and find clinical details of known cases. As a result, we may have underestimated the incidence of decompression illness. There was also difficulty in obtaining accurate chamber running logs from outlying training centres, so we restricted our incidence estimate to AVMED.

A frequently encountered difficulty in studies of the incidence of decompression illness is confirming the diagnosis. Decompression illness presents in diverse ways, often with vague symptoms (eg, joint pain) that may have other causes. There is no specific test for decompression illness, but response to treatment often assists in the diagnosis.

Incidence

Before 1994, the incidence of decompression illness at AVMED was reported as 0.13%.³³ For the period January–August 1995, the same report stated an incidence of 1.4%. The reported incidence for the period April 1997 to June 1998 was 0.97% (TL Smart, unpublished data). The incidence of 0.39% calculated in this study is nearly four times greater than the average incidence noted in other studies or reported in the ADF before 1994, but noticeably less than the 1995 and 1997–1998 figures. Because this study reviewed a longer period and involved a more complete search of records, its incidence estimate is likely to be closer to the true incidence seen at AVMED.

Consistent with previous studies,^{8-10,14,17} type 1 decompression illness was the commoner presentation. Type 2 decompression illness presented with predominantly neurological symptoms. The 8.8% incidence of long-term residual effects in affected personnel is higher than rates of 0.7% and 2.3% reported by others.^{6,31} Due to the lack of follow-up clinical data it is difficult to speculate on why this is so.

The type C chamber flight, being the profile with the highest simulated altitude, has the highest incidence of decompression illness. Bason et al state that the risk of decompression sickness at 40 000 feet is 3.5 times greater than at 25 000 feet.⁸ A confounding factor in our study is that students usually undertook the type C chamber flight after completing both type A and B profiles on two previous days. The incidence of decompression illness could be an effect of multiple exposures, rather than of altitude *per se*. Similarly, presentations after the type B chamber flight at 15 000 feet (well below the decompression illness “threshold”) may be due to recurrent exposure following a type A exposure 24 hours previously. Exposure to type B chamber flights alone was uncommon, so it is difficult to confirm this hypothesis.

6: Number of cases and incidence of decompression illness in the AVMED chamber by type of chamber flight, 1989–2001

Run type	Exposures	Cases	Incidence
A	6129	22	0.36%
B	3671	12	0.33%
C	912	7*	0.77%
Other	139	1	0.72%
Total	10851	42	0.39%

*1 case in 2001 was an instructor exposed to only 17 000 feet in the chamber man-lock during a type C chamber flight.

The 1995 “epidemic”

The ADF experienced a cluster of decompression illness cases from January to July 1995, when 10 definite and 3 probable cases of decompression illness were reported at the AVMED and Edinburgh chambers. Occurrences of clusters of this type have been reported previously, both in training and operationally, and have been referred to in the literature as “epidemics”.^{34,35} The US Navy experienced two “blitzes of bends” in 1988 and 1990. In the first epidemic, 6 cases occurred in 2 weeks, and in the second, 5 cases. The incident chamber was shut down and a thorough investigation carried out on both occasions, but no common factors were found.³⁶

The 1995 ADF outbreak of decompression illness occurred only months after a number of significant changes were implemented. In particular, and contrary to expectation, the rate of decompression illness appeared to increase after introduction of prebreathing of 100% oxygen for all exposures above 18 000 feet. Scientific evidence demonstrates that prebreathing significantly reduces, rather than increases, the incidence of decompression illness.^{15,32}

Other changes made immediately before the start of the 1995 “epidemic”, which may have affected the incidence of decompression illness, were:

- An increased number of aircrew were trained in early 1995 after the move of AVMED to RAAF Edinburgh and more stringent enforcement of aviation medicine training requirements.
- Training was conducted in a new location, resulting in longer flights to and from the training centre, usually on commercial aircraft.
- A more aggressive approach to management of decompression illness was adopted (“If in doubt, recompress”). This may have increased the identification of cases.
- Aeromedical disposition outcomes following an episode of uncomplicated decompression illness were liberalised. Previously, an episode of decompression illness would result in permanent cabin altitude restrictions, and this could severely affect an individual’s career. We have heard anecdotal reports of aircrew who had symptoms of decompression illness but did not report them, for fear of the implications. After 1994, the environment was more conducive to reporting symptoms.

- AVMED pre-exposure briefing emphasised more strongly the risks and symptoms of decompression illness, which may have increased reporting.

Another possible reason for increased reporting is a form of epidemic hysteria. This phenomenon is defined as “a constellation of symptoms suggestive of organic illness, but without an identifiable cause, that occurs between two or more people who share beliefs related to these symptoms”.³⁷ While not suggesting that the symptoms reported were non-organic, the publicity generated by an increased occurrence of decompression illness after 1994 may have unduly emphasised the seriousness of the condition, and thus encouraged people to report.

Before 1994, decompression illness management protocols did not provide guidelines for managing delayed onset decompression illness. In addition, it was considered that observation and delivery of 100% oxygen was an appropriate treatment for “pain only” (type 1) decompression illness.³⁸ Published reports of decompression illness management then indicated consideration of hyperbaric therapy for all cases where the symptoms persisted at ground level or commenced after the flight.⁶ Subsequent research has suggested that hyperbaric therapy may not be necessary for type 1 decompression illness if symptoms resolve fully on 100% oxygen.³⁹ However, the decision to implement more aggressive management was not only the safest option but was based on contemporary knowledge.

The consequences of this change in management were undoubtedly that more cases of suspected decompression illness were discussed with hyperbaric specialists and subsequently referred for treatment. Therefore, we conclude that cases that might previously have been treated locally and discharged as “possible decompression illness” were now definitively diagnosed as decompression illness on the basis of their response to hyperbaric treatment.

It is likely that many factors played a role in the 1995 “epidemic”, including heightened awareness, increased willingness on the part of students to report symptoms, and an increased tendency to treat. It is also possible that other training centres worldwide are underreporting cases, leading to low incidence estimates. There is a striking difference between decompression illness incidence reported by aircrew in operational and training environments, which is less than that found in prospective experimental altitude studies.⁴⁰

Training risks

Despite AVMED introducing many safety measures, the risks of hypobaric chamber training remained. The only method available to further reduce the risk was to cease training above 18000 feet simulated altitude. The COMCARE Prohibition Notice issued in 2001 forced AVMED to pursue alternative methods of delivering hypoxia training, and the result was the development of CADO.⁴¹ The validation of CADO as a means of hypoxia familiarisation training is the subject of current research.

COMCARE’s action was based on the inability of the ADF to demonstrate conclusively that the benefits of hypobaric chamber training outweigh the risks. A risk–benefit analysis was first proposed in 1995, but has proven difficult to accomplish. The risks of decompression illness resulting from training can be estimated, and an assessment of relative risk associated with the RAAF type A chamber flight was conducted in 1996 using predictive software (personal communication, RE Moon, Associate Professor of Anesthesiology and Pulmonary Medicine, Duke University Medical Centre). The estimated overall risk of decompression illness for this profile was 0.4% without prebreathing of 100% oxygen and 0.26% with a 30-minute prebreathing. This compared favourably with the USAF type 1 altitude training profile that had an estimated decompression illness risk of 5.3%.

The benefits of hypoxia training are subjective. Anecdotal evidence suggests that most military aircrew find hypobaric chamber training beneficial. In a survey of 63 RAN and RAAF aircrew for the AVMED report of 2001, 58 believed hypoxia training to be of value and that the benefits outweighed the risks,⁴² including a pilot who had suffered decompression illness following a chamber flight. Thirty aircrew had experienced hypoxia in flight and believed that their hypoxia training aided them in recognising symptoms and responding to the emergency. Only 2 aircrew suggested that an alternative type of hypoxia training should be implemented.

A review of ADF operational hypoxia incidents found 27 reports from 1990 to 2001, involving 29 aircrew.⁴³ Two aircrew lost consciousness, and there was one fatality that was probably the result of hypoxia. However, most trained aircrew recognised their own symptoms or signs in others and took corrective action.

Hypoxia familiarisation training is likely to increase the ability to recognise symptoms and successfully deal with hypoxic emergencies, and this saves lives. But is the training achieved by low-pressure chamber exposure to induce hypoxia worth the risk of decompression illness?

Defining the limits of acceptable risk in military training is difficult. A recent review of military parachute related injuries revealed a worldwide injury rate of 0.56%,⁴⁴ and an Australian study revealed an even higher rate of 0.71%.⁴⁵ We conducted an analysis of data from the ADF Directorate of Flying Safety, which revealed that from 1984 to 2001, 33 aircraft accidents involving 68 aircrew occurred in ADF flight training units. Three reports lacked data on the occupants or injuries, but in the other accidents 21 aircrew had minor injuries, 1 had serious injuries, and 10 were killed. Flight training is a higher risk activity than hypobaric chamber training.

AVMED proposes to undertake a formal aviation risk management assessment of hypobaric training, to permit more informed decisions regarding future options.

Studies of various alternative methods of hypoxia training continue, including the ADF-developed CADO.^{41,46,47} Hypoxia can be induced at lower simulated altitudes, or even at ground level pressures, but whether these techniques retain adequate fidelity to the experience of hypoxia in flight is unproven.

Conclusions

The rate of decompression illness from ADF hypobaric chamber training from 1984 to 2001 was significantly higher than that reported elsewhere. This was due in part to the cluster of decompression illness cases experienced in 1995, for which contributory factors have been identified. AVMED took appropriate action to improve the safety of training, but some of these measures may have increased reporting and thus increased the apparent incidence of decompression illness.

The benefits of hypoxia training are demonstrable, although difficult to quantify. The risks associated with the hypobaric chamber method of hypoxia training are quantifiable to a certain extent, but the appropriate balance between risks and benefits is not clear. A more detailed risk–benefit analysis should help to clarify whether hypobaric chamber training, incorporating appropriate safety measures, will remain a useful training method.

Acknowledgements

We acknowledge the valuable assistance rendered by the staff of the Institute of Aviation Medicine Orderly Room, the staff of Development Flight, Mrs Josie Marron of the Defence Library Service, and Mr John Crawley from the Directorate of Flying Safety, in researching this work. Thanks also to Dr Bhupinder Singh for his review of the manuscript and eye for detail. The opinions expressed in this paper are those of the authors and do not represent the policy or opinion of the Royal Australian Air Force, the Department of Defence, Defence Health Service, or the Australian Government.

References

1. Harding RM. Hypoxia and hyperventilation. In: Ernsting J, Nicholson AN, Rainford DJ, editors. *Aviation medicine*. Oxford: Butterworth Heinemann, 1999.
2. Rayman RB, McNaughton GB. Hypoxia: USAF experience 1970–1980. *Aviat Space Environ Med* 1983; 54: 357-359.
3. Island RT, Fraley EV. Analysis of USAF hypoxia incidents January 1976 through March 1990. In: Proceedings of the 31st Annual SAFE Symposium, Las Vegas, 8–10 Nov 1993.
4. North Atlantic Treaty Organization. Aeromedical aspects of aircrew training. RTO Meeting Proceedings 21, RTO/NATO, 1999. Available at: <http://www.rta.nato.int/Rdp.asp?RDP=RTO-MP-021> (accessed Feb 2004).
5. Air Standardization Coordinating Committee. Air standard 61/101/3. *Aviation medicine/physiological training of aircrew*. Ch 2. May 1990.
6. Davis JC, Sheffield PJ, Schuknecht L, et al. Altitude decompression sickness: hyperbaric therapy results in 145 cases. *Aviat Space Environ Med* 1977; 48: 722-730.
7. Neubauer JC, Dixon JP, Herndon CM. Fatal pulmonary decompression sickness: a case report. *Aviat Space Environ Med* 1988; 59: 1181-1184.
8. Bason R, Pheeny H, Dully FE. Incidence of decompression sickness in Navy low-pressure chambers. *Aviat Space Environ Med* 1977; 47: 995-997.
9. Bason R, Yacavone D. Decompression sickness: US Navy altitude chamber experience 1 October 1981 to 30 September 1988. *Aviat Space Environ Med* 1991; 62: 1180-1184.
10. Baumgartner N, Weien RW. Decompression sickness due to USAF altitude chamber exposure (1985–1987). In: Pilmanis AA, editor. Proceedings of the 1990 Hypobaric Decompression Sickness Workshop. Brooks Air Force Base, TX: Air Force Systems Command, 1992: 363-369 (rep. no. AL-SR-1992-0005).
11. Furry DE. Incidence and severity of altitude decompression sickness in Navy hospital corpsmen. *Aerospace Med* 1973; 44: 450-452.
12. Harding RM. DCS experience outside North America. In: Pilmanis AA, editor. Proceedings of the 1990 Hypobaric Decompression Sickness Workshop. Brooks Air Force Base, TX: Air Force Systems Command, 1992: 457-463 (rep. no. AL-SR-1992-0005).
13. Ohri N, Takeuchi A, Tong A, et al. Physiological incidents during 39 years of hypobaric chamber training in Japan. *Aviat Space Environ Med* 2002; 73: 395-398.
14. Piwinski SE, Cassingham R, Mills J, et al. Decompression sickness incidence over 63 months of hypobaric chamber operation. *Aviat Space Environ Med* 1986; 57: 1097-1101.
15. Rice GM, Vacchiano CA, Moore JL, Anderson DW. Incidence of decompression sickness in hypoxia training with and without 30-min O₂ prebreathe. *Aviat Space Environ Med* 2003; 74: 56-61.
16. Valdez CD. The FAA altitude chamber training flight profiles: a survey of altitude reactions 1965–1989. In: Pilmanis AA, editor. Proceedings of the 1990 Hypobaric Decompression

- Sickness Workshop. Brooks Air Force Base, TX: Air Force Systems Command, 1992: 457-463 (rep. no. AL-SR-1992-0005).
17. Weien RW, Baumgartner N. Altitude decompression sickness: hyperbaric therapy result in 528 cases. *Aviat Space Environ Med* 1990; 61: 833-836.
18. Pilmanis A. Altitude decompression sickness. In: Moon RE, Sheffield PJ, editors. *Treatment of Decompression Illness*. Proceedings of the forty-fifth Undersea and Hyperbaric Medical Society Workshop, 1996: 25-42.
19. Fryer DI, Roxburgh HL. Decompression sickness. In: Gillies JA, editor. *A textbook of aviation physiology*. Oxford: Pergamon Press, 1965: 134.
20. Kumar KV, Waligora BS, Calkins DS. Threshold altitude resulting in decompression sickness. *Aviat Space Environ Med* 1990; 61: 685-689.
21. Rayman RB, McNaughton GB. Decompression sickness: USAF experience 1970-1980. *Aviat Space Environ Med* 1983; 54: 258-260.
22. Voge VM. Probable bends at 14,000 feet: a case report. *Aviat Space Environ Med* 1989; 60: 1102-1103.
23. Pilmanis AA, Webb JT, Kannan N, Balldin U. The effect of repeated altitude exposures on the incidence of decompression sickness. *Aviat Space Environ Med* 2002; 73: 525-531.
24. Vann RD, Denoble P, Emmerman MN, Corson KS. Flying after diving and decompression sickness. *Aviat Space Environ Med* 1993; 64: 801-807.
25. Sulaiman ZM, Pilmanis AA, O'Connor RB. Relationship between age and susceptibility to altitude decompression sickness. *Aviat Space Environ Med* 1997; 68: 695-698.
26. Arthur DC, Margulies RA. The pathophysiology, presentation, and triage of altitude-related decompression sickness associated with hypobaric chamber operation. *Aviat Space Environ Med* 1982; 53: 489-494.
27. Gibbons JA, Ramsey CS, Wright JK, Pilmanis AA. Case history of serious altitude decompression sickness following rapid rate of ascent. *Aviat Space Environ Med* 2003; 74: 675-678.
28. Clamann HG. Decompression sickness. In: Randel HW, editor. *Aerospace Medicine* 2nd edition. Baltimore: Williams & Wilkins, 1971: 108.
29. Heimbach RD, Sheffield PJ. Decompression sickness and pulmonary overpressure accidents. In: DeHart R, editor. *Fundamentals of aerospace medicine*. Philadelphia: Lea & Febiger, 1985: 132-161.
30. Macmillan A. Sub-atmospheric decompression sickness. In: Ernsting J, Nicholson AN, Rainford DJ, editors. *Aviation medicine*. Oxford: Butterworth Heinemann, 1999: 19-25.
31. Wirjosemito SA, Touhey JE, Workman WT. Type II altitude decompression sickness (DCS): US Air Force experience with 133 cases. *Aviat Space Environ Med* 1989; 60: 256-262.
32. Stegman BJ. Prebreathing theory and history. In: Pilmanis AA, editor. Proceedings of the 1990 Hypobaric Decompression Sickness Workshop. Brooks Air Force Base, TX: Air Force Systems Command, 1992: 221-232 (rep. no. AL-SR-1992-0005).
33. Emonson DL. Paper presented to Aviation Medical Society of Australia and New Zealand Annual Scientific Meeting, Adelaide, 1995.
34. Butler WP. Epidemic decompression sickness: case report, literature review, and clinical commentary. *Aviat Space Environ Med* 2002; 73: 798-804.
35. Piwinski SE, Mitchell RA, Goforth GA, et al. A blitz of bends: decompression sickness in four students after hypobaric chamber training. *Aviat Space Environ Med* 1986; 57: 600-602.
36. Clark JB. DCS incidence and reporting, session four – discussion #5. In: Pilmanis AA, editor. Proceedings of the 1990 Hypobaric Decompression Sickness Workshop. Brooks Air Force Base, TX: Air Force Systems Command, 1992: 386 (rep. no. AL-SR-1992-0005).
37. Boss LP. Epidemic hysteria: a review of the published literature. *Epidem Rev* 1997; 19: 233-243.
38. Capps RA. Report on the enquiry investigating a matter concerning decompression illness with respect to (name deleted), 1993. ADF Health Service report (on file at AVMED).
39. Rudge FW. The role of ground level oxygen in the treatment of altitude chamber decompression sickness. *Aviat Space Environ Med* 1992; 63: 1102-1105.
40. Ryles MT, Pilmanis AA. The initial signs and symptoms of decompression sickness. *Aviat Space Environ Med* 1996; 67: 983-989.
41. Cable GG, Singh B, Pinch I. Combined altitude depleted oxygen system for safe hypoxia training of aviators. *Aviat Space Environ Med*. In press.
42. AVMED Report 3/2001. ADF hypobaric chamber training: consideration of dangers, benefits, options, and alternatives. RAAF Institute of Aviation Medicine, RAAF Base Edinburgh, 2001.
43. Cable GG. In-flight hypoxia incidents in military aircraft: causes and implications for training. *Aviat Space Environ Med* 2003; 74: 169-172.
44. Bricknell MCM, Craig SC. Military parachute injuries: a literature review. *Occup Med* 1999; 49: 17-26.
45. Farrow GB. Military static line parachute injuries. *Aust N Z J Surg* 1992; 62: 209-214.
46. Sausen KP, Wallick MT, Slobodnick B, et al. The reduced oxygen breathing paradigm for hypoxia training: physiological, cognitive and subjective effects. *Aviat Space Environ Med* 2001; 72: 539-545.
47. Zwart B. A proposal to use ROBE for hypoxia refresher training. USAFSAM/FEH After Action Report 20020403.

(Received 12 Sep 2003, accepted 15 Jan 2004)

