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ORIGINAL ARTICLE

HIGH ALTITUDE CHAMBER TRAINING FOR MILITARY FLIGHT PERSONNEL - ALTITUDE DCS RISK ASSESSMENT BY MEANS OF ECHOCARDIOGRAPHIC DETECTION OF GAS BUBBLES

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Introduction: The objective of the study consisted in the assessment of the risk of decompression sickness (DCS).

Methods: The study was conducted in 45 healthy males aged 24-45 years. A total of 64 exposures to low pressure were performed in high altitude chambers.

Results: No clinical symptoms of DCS were observed in either patient following high altitude exposure.

Discussion: A 30-minute inhalation of 100% oxygen appears to provide sufficient prevention against clinical symptoms of DCS in high altitude training with the ceiling of 7500 m.a.s.l.

Conclusions: Extension of saturation periods should be considered for exposures at the ceiling of 10000 m.a.s.l.

Keywords: decompression sickness, hypoxia, pilots

INTRODUCTION

Professional preparation of the flight personnel to perform complex aviation tasks requires appropriate medical flight simulators being used in aviation training. The performance characteristics of such simulators must ensure the safety of training while enabling the subjects to undergo training in conditions possibly closest to the real-life conditions and possibly most faithfully imitating the actual flight settings. Demonstration of symptoms of high altitude hypoxia and rapid decompression symptoms using high-altitude chambers (HAC) and rapid decompression chambers (RDC) is a part of

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routine aviation medicine training of military flight personnel at the Military Institute of Aviation Medicine (MIAM). Both forms of practical training using HAC and RDC are associated with a low likelihood of development of DCS symptoms in subjects; however, potential consequences of such symptoms might be harmful to subjects' health.

Decompression sickness (DCS, also known as divers' disease or the bends) is a syndrome of pathological symptoms developing as a result of production of gas bubbles (mostly nitrogen bubbles) within tissues and systemic fluids as the result of reducing barometric pressure, most commonly encountered while diving or working in caissons. High-altitude DCS is a particular form of DCS occurring after exposure to reduced atmospheric pressure. Both forms of DCS may be manifested by mild symptoms (type 1, skin and joint symptoms) or severe symptoms (type 2, symptoms within the circulatory, respiratory, or nervous systems). Compared to diving, high-altitude exposure is associated with an incommensurately lower risk of DCS while manifestations of high altitude DCS symptoms are milder, with most cases reported to be type 1 DCS (>94%, according to various sources) [2]. Cases of severe aviation-related DCS are usually manifested by cerebral symptoms rather than spinal symptoms as in the case of diving-related DCS [1,3,6]. First symptoms of DCS may develop after 5 minutes at high altitudes while the most common onset times range between 20 and 60 minutes of exposure [1,3,4]. The development of DCS may be promoted by a number of accompanying factors such as repeated exposure to low pressures at short time intervals (Tab. 1.).

In most cases, the risk of high altitude DCS in aviation is a result of emergency situations involving decompression of pilot's cabin at high altitudes. Air forces of some countries are equipped with aircrafts such as U2, F22, V22 that, due to specific nature of their tasks (involving high flight ceilings, long missions and cabin pressurization parameters) generate a significant risk of DCS to the crews despite the correct preparation of individual missions (Tab. 2.).

Most cases of severe high altitude DCS in military aviation is associated with U2 aircraft missions. (Example U2 mission profile Tab. 2a [2]).

The main risk of DCS in regular airborne tasks performed within Polish Air Forces is associated with high altitude parachuting (HALO/HAHO). Decompression sickness may occur in both parachuters and the transport aircraft crew. In this types of tasks, parachute jumps may be made from altitudes of as high as 10000 m.a.s.l, in pressurised cabin conditions. The probability of development of DCS symptoms increases with the height and times spent at the altitude. However, the risk of DCS increases significantly at altitudes of above 5500 m.a.s.l [3] (with the exception of flights after diving, see Tab. 3.).

HAC/RDC training is provided in conditions typical at altitudes much above that ceiling, i.e. 7500 m.a.s.l. within the medium-risk zone of DCS. In case of exposures to altitudes of 10000 m.a.s.l.,

Tab. 1. Factors promoting the development of DCS symptoms.

- repeated exposure to reduced barometric pressure
- fast altitude climbing
- time of flight at high altitude
- hypoxia
- low temperatures
- dehydration
- physical exertion
- age
- body composition - obesity
- history of trauma or surgeries
- overall health: smoking, alcohol intake, drugs taken, chronic diseases
- individual predispositions
- diving before the flight

Tab. 2. Methods for preventing high altitude DCS.

- pressurized aircraft cabins
- pressure suits
- nitrogen desaturation
- selection of pilots
- restrictions for flights above 5500 m.a.s.l.

Tab. 2a. U2 mission profile.

• altitude above 70000 ft (21336 m)
• pressurized cockpit (differential pressure 196.5 mmHg)
• pilot exposed to: 29000 to 30000 ft (222.3 mmHg)
• exposure time: 8-12 hours
• standard DCS Prevention Measure
- 1-hour tissue nitrogen desaturation w/ 100% O2
- pressure outfit (181 mmHg)

Tab. 3. Flights after diving - restrictions.

DIVING WITHOUT DECOMPRESSION STOPS
< 1 h after diving - max. ceiling 300 m
1- 2 h after diving - max. ceiling 1500 m
> 2 h after diving - max. ceiling 2400 m
DIVING REQUIRING DECOMPRESSION STOPS
< 4 h after diving - max. ceiling 300 m
4- 8 h after diving - max. ceiling 1500 m
8- 24 h after diving - max. ceiling 5000 m
> 24 h after diving - no max. ceiling limit

the risk of high altitude DCS symptoms is considered to be relatively high. The percentage rate of DCS cases developed as a result of high altitude exposures during routine aviation medicine HAC trainings is estimated at 0.38 to 2% of the population of subjects [3].

In order to provide DCS prevention, high altitude exposures above 6000 m.a.s.l. should be preceded by sufficiently long desaturation to replace nitrogen with oxygen within the pilot's tissues (continuous breathing with 100% oxygen for times depending on the planned ceiling, e.g. 30 minutes for the ceiling of 7500 m.a.s.l.). When properly conducted, desaturation should effectively reduce the risk of DCS at the assumed exposures by as much as tens of percent [4,5]. The aim of the study was to assess the efficacy of the established methods of DCS prevention during the aviation medical trainings using low-pressure simulators available at MIAM (as per the Instruction of Aviation Medicine training for the Polish Armed Forces Flight Personnel [6]).

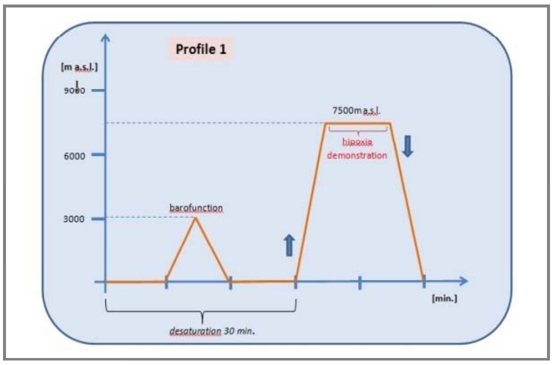

Fig. 1 HAC 7500 m.a.s.l.

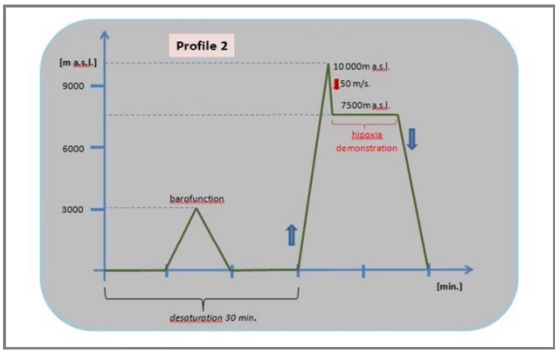

Fig. 2. HAC 10000 m.a.s.l.

During the aviation medical training, the flight personnel was exposed to low barometric pressures in high altitude chambers. Demonstration of hypoxia symptoms is performed at an altitude level of 7500 m.a.s.l. (ca. 280 mmHg) on each subject (Fig. 1.). There are also profiles of high altitude exposures of 10000 m.a.s.l. These refer to paratroopers performing parachuting from altitudes above 4000 m.a.s.l. Flying personnel of pressurized aircrafts undergo a demonstration of rapid decompression (Fig. 2). Trainings for pressurized cabin aircraft crews are expanded by demonstration of rapid decompression. Trainings are conducted in rapid decompression chamber (RDC) and consist of exposure subjects to rapid changes of pressures from the altitude of 3000 to 7000 m.a.s.l within 2 or 10 seconds. (Fig. 3.).

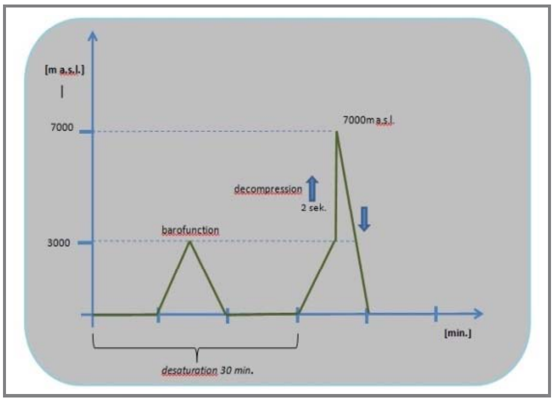

Fig. 3. RDC 3000-7000 m.a.s.l. - 2 sec.

METHODS

The study was conducted with 45 healthy male volunteers from 24 to 49 years old, fit-to-flight and without history of DCS symptoms. A total of 64 exposures to low pressure were performed in hypobaric chambers (HAC and RDC) of MIAM as a part of an aeromedical training.

The subjects were participants in routine aeromedical training. High performance aircraft's pilots, transport aircrew and high altitudes parachuters took part in the study. Exposures to reduced barometric pressures were performed in the following groups:

- 19 individual RDC exposures from 3000 to 7000 m.a.s.l. decompression during 2 seconds and trainees were subjected to HAC exposure at 7500 m.a.s.l. level within the next 24 hours;
- 30 exposures at 7500 m.a.s.l.;
- 15 exposures at 10000 m.a.s.l.

Biometric and medical data were collected during the test. Echocardiography examination was performed after each high altitude exposure focused on screening the right atrium and ventricle towards presence of gas bubbles. DCS risk was classified on the basis of the Modified Spencer Scale (Tab. 4.) [1,6].

Tab. 4. Modified Spencer scale.

Grade 0	complete lack of bubbles
Grade 1	bubbles occasionally observed, vast majority of cardiac cycles bubble-free
Grade 2	bubbles (singly or in groups) observed in many but less than half of the cardiac cycles
Grade 3	all cardiac cycles contain bubbles in showers, but not overriding heart signals
Grade 4	bubbles sounding continuously during systole and diastole, overriding amplitude of normal heart signals

RESULTS

No clinical symptoms of decompression sickness were observed in any of the subjects following high altitude exposure - no musculoskeletal, skin, cardiovascular, respiratory, or nervous system symptoms were either observed or reported by subjects themselves.

Gas bubbles were detected in ECHO scans of 4 out of 30 subjects following the exposure to low pressure corresponding to the altitude of 7500 m.a.s.l. (Fig. 4.). Three patients were classified as grade I and one patient was classified as grade II due to DCS Spencer scale. In all of these cases, the subjects had been subjected to rapid decompression training (RDC) on the previous day.

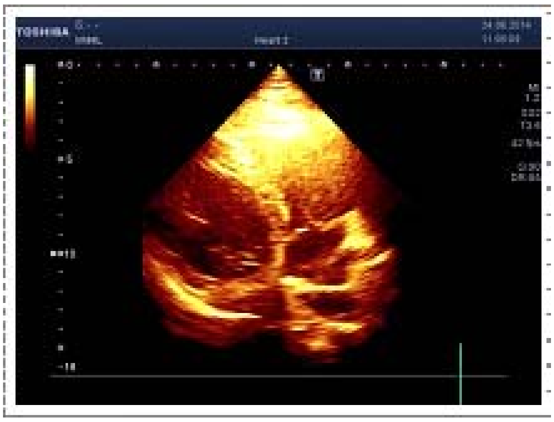

Fig. 4. ECHO scan of a subject.

No gas bubbles were detected within the right atrium in ECHO scans immediately after RDC exposure of either of 19 subjects. Gas bubbles were detected in 5 out of 15 subjects exposed to low barometric pressures corresponding to the altitude of 10000 m.a.s.l. Three patients were classified as grade I and two patients were classified as grade II due to DCS Spencer scale.

DISCUSSION AND CONCLUSIONS

A 30-minute saturation of 100% oxygen (tissue nitrogen desaturation) appears to provide sufficient prevention against clinical symptoms of DCS in high altitude training with the level of 7500 m.a.s.l. Of note is the fact that the group of subjects who were classified with DCS Spencer scale as grade higher than 0 had been exposed in two profiles: rapid decompression and high altitude hypoxia (subjects participating in the training at the altitude of 10000 m.a.s.l. had not been subjected to previous rapid decompression training). The fact may be explained by accumulation of nitrogen bubbles within the body during repeated exposures resulting from incomplete elimination of gas bubbles formed upon rapid decompression. However, clear conclusions can not be drawn due to the low number of subjects examined. With no doubt, similar accumulation of gas bubbles may occur in pilots/aircraft crew members subjected to repeated low pressure exposures in short time intervals. In such cases, progressive accumulation of gas bubbles may, in certain unfavorable conditions (supersaturation), be manifested by DCS symptoms. In this regard that requires further study. The requirement of 24-hour intervals between high altitude exposures, is an efficient method of preventing accumulation of nitrogen bubbles.

A 30-minute (at rest) tissue nitrogen desaturation using 100% oxygen may be insufficient for 10000 m.a.s.l. exposures. Despite no clinical symptoms of DCS being observed in the subjects, a significant increase of cases qualified as Spencer grade I and II was observed (a 2.5-fold increase in comparison to the altitude of 7500 m.a.s.l. despite lack of earlier low pressure exposure in case of 10000 m.a.s.l. training).

Extension of 100% oxygen saturation periods should be considered for exposures at the level of 10000 m.a.s.l. It is also worthwhile to assess the usefulness of echocardiographic follow-up in patients with symptoms of DCS occurring during the exposure and not resolving after descent. Similar recommendations of echocardiographic diagnostics should be applied in instructors subjected to low pressure exposures more than two times a week, even despite absence of clinical manifestations of DCS.

AUTHORS' DECLARATION:

Study Design: Andrzej Jarosz, Tomasz Ameljańczyk, Grzegorz Kempa; **Data Collection:** Andrzej Jarosz, Tomasz Ameljańczyk, Grzegorz Kempa; **Statistical Analysis**: Andrzej Jarosz, Tomasz Ameljańczyk, Grzegorz Kempa; **Manuscript Preparation:** Andrzej Jarosz, Tomasz Ameljańczyk, Grzegorz Kempa; **Funds Collection:** Andrzej Jarosz, Tomasz Ameljańczyk, Grzegorz Kempa. The Authors declare that there is no conflict of interest.

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