RESEARCH ARTICLE

Inner ear decompression sickness in Finland: a retrospective 20-year multicenter study

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ABSTRACT

Introduction: Inner ear decompression sickness (IEDCS) is a condition from which only a minority of patients recover completely, the majority ending up with mild to moderate residual symptoms. IEDCS has been reported after deep technical dives using mixed breathing gases, and moderate recreational dives with compressed air as the breathing gas. Considering this and the high proportion of technical diving in Finland, a comparison between IEDCS cases resulting from technical and recreational dives is warranted.

Methods: This is a retrospective examination of IEDCS patients treated at Hyperbaric Center Medioxygen or National Hyperbaric Centre of Turku University Hospital from 1999 to 2018. Patients were included if presenting with hearing loss, tinnitus, or vertigo and excluded if presenting only with symptoms of middle ear or cerebellar involvement. Patients were divided into technical and recreational divers, based on incident dive.

Results: A total of 89 (15.6%) of all DCS patients presented with IEDCS, two-thirds treated during the latter decade. The most common predisposing factors were consecutive days of diving (47.2%), multiple dives per day (53.9%), and factors related to an increase in intrathoracic pressure (27.0%). The symptoms were cochlear in 19.1% and vestibular in 93.3% of cases, symptoms being more common and severe in technical divers. Complete recovery was achieved in 64.5% of technical and 71.4% of recreational divers.

Conclusion: The incidence of IEDCS in Finland is increasing, most likely due to changing diving practices. A comprehensive examination should be carried out after an incident of IEDCS in all cases, irrespective of clinical recovery.

INTRODUCTION

Decompression sickness (DCS) is a diving disorder resulting from a rapid reduction in ambient pressure, which causes the total sum of dissolved gas partial pressures (the tissue pressure) to temporarily exceed that of the ambient environment [1]. When this pressure differential is substantial enough, inert gas bubbles form in affected tissues, and when this formation of bubbles is substantial enough, symptoms of DCS begin to develop [2].

Inner ear decompression sickness (IEDCS) is a subtype of DCS characterized by symptoms of cochleovestibular involvement, such as hearing loss, tinnitus and vertigo, with more severe cases including nausea and vomiting. The symptoms may appear in isolation or in conjunction with other symptoms, and only a minority of patients recover completely, the majority ending up with mild to moderate residual symptoms [3,4].

The earliest cases were reported in connection with technical diving [5]. These dives were characterized by exceptionally deep depths and the use of helium-rich breathing gases with symptoms appearing on ascent, in some cases precipitated by an isobaric switch from helium-rich to nitrogen-rich breathing gases during decompression. These cases have been interpreted to result from local supersaturation within the membranous labyrinth, in some cases possibly augmented by isobaric gas counterdiffusion [5-8].

KEYWORDS: decompression; diving; ENT; epidemiology; labyrinth

The more recent cases have been reported in connection with recreational diving [9-15]. These dives have been characterized by relatively modest depths and use of compressed air as the breathing gas throughout the dive. The symptoms have appeared immediately or shortly after surfacing, and a high proportion of patients have been identified with (moderate to large) right-to-left shunts. These cases have been interpreted to result from local supersaturation within the membranous labyrinth, in most cases augmented by inert gas bubbles reaching the labyrinthine artery [7,8].

To summarize, some cases have resulted from deep technical dives with mixed breathing gases and isobaric gas switches during decompression, and some from moderate recreational dives with air as the breathing gas throughout the dive. Considering these distinctly different circumstances and the special features of the Finnish diving environment (a relatively small proportion of recreational dives and a high proportion of deep technical dives in mines and quarries) [16], a comparison between IEDCS after recreational and technical dives is warranted. Therefore, the aims of this study were: a) to provide a detailed description of all IEDCS cases in Finland over the 20-year observation period; and b) to investigate the differences between IEDCS cases after technical and recreational dives.

METHODS

Ethical considerations

The study was conducted in accordance with the Declaration of Helsinki and approved by the Finnish Institute for Health and Welfare (THL/2014/5.05.00/2018). The need for informed consent was waived, as the data analysis was retrospective and the research subjects were not treated experimentally.

Study design

A retrospective examination of all IEDCS patients treated at Hyperbaric Center Medioxygen or National Hyperbaric Centre of Turku University Hospital from 1999 to 2018 was conducted (representing more than 95% of all IEDCS patients treated in Finland during the time period [16]). Patients were included in the study if presenting with any combination of symptoms consistent with IEDCS (hearing loss, tinnitus, or vertigo) and excluded if presenting with non-definitive cochleovestibular symptoms only, more consistent with middle ear (i.e., pressure or pain sensations in the ears) or cerebellar involvement (i.e., mild unsteadiness, dizziness, or ataxia). Patients with symptoms and signs of inner ear barotrauma (i.e., middle ear equalization difficulties *and* middle ear barotrauma after dives with a very low risk of DCS) were also excluded.

Data on patient characteristics, history of DCS incidents, and history of IEDCS incidents were retrieved from the patient records. The qualification level of each diver was also documented, determined as "highly qualified" or "less qualified" as defined previously [16]. The incident dive type was classified as recreational or technical, defined as technical when utilizing: 1) mixed breathing gases (trimix); 2) a closed-circuit rebreather; or 3) a decompression plan and the use of decompression gases for accelerated decompression.

Data on incident dive depth and duration were also retrieved, as well as data on the possible risk factors for IEDCS. The risk factors were classified as ongassing-related (consecutive days of diving, multiple dives per day); offgassing-related (dehydration or feeling cold during the incident dive; uncontrolled ascent from the incident dive; altitude exposure after the incident dive) or related to a rise in intrathoracic pressure (middle ear equalization difficulties and forceful Valsalva maneuvers during the incident dive; physical exertion such as climbing to a boat or lifting/carrying heavy diving equipment after the incident dive) and the possible embolization of inert gas bubbles through a right-to-left shunt.

Data on the symptoms during or after the incident dive were also retrieved, including a detailed analysis of any cochleovestibular symptoms at the initial stage and at physical examination, as well as the classification of other symptoms as either cerebral, spinal, pulmonary, sensorineural, osteomyoarticular, or cutaneous in origin. In addition, details regarding the utilization of first aid 100% oxygen (FAO_2), delay to recompression, the first recompression protocol used, and treatment outcomes both at discharge and at follow-up were documented, when available. In addition, the treatment outcomes (at discharge) were categorized as described previously [14], forming the initial functional impairment and residual functional impairment scores (iFIS and rFIS, respectively). All treatment outcomes focused on the cochleovestibular recovery of patients.

Statistical analysis

All statistical analyses were performed using SPSS Statistics for Windows, version 27.0, released 2020 (IBM Corp, Armonk, New York, U.S.). A two-tailed p-value of <0.05 was interpreted to indicate statistical significance.

Table 1. Characteristics of incident dives

	all (n=89)	REC (n=57)	TECH (n=32)	p-value
dive qualification				
< CMAS P3 or equivalent	39 (43.8%)	35 (61.4%)$_a$	4 (12.5%)$_b$	<0.001
≥ CMAS P3 or equivalent	50 (56.2%)	22 (38.6%)$_a$	28 (87.5%)$_b$	
dive gas				
air	45 (50.6%)	41 (71.9%)$_a$	4 (12.5%)$_b$	<0.001
nitrox	26 (29.2%)	16 (28.1%)	10 (31.3%)	
trimix	18 (20.2%)	0 (0.0%)$_a$	18 (56.3%)$_b$	
dive depth[x]				
< 30 msw	37 (42.0%)	35 (62.5%)$_a$	2 (6.3%)$_b$	<0.001
30 – 60 msw	42 (47.7%)	21 (37.5%)$_a$	21 (65.6%)$_b$	
> 60 msw	9 (10.2%)	0 (0.0%)$_a$	9 (28.1%)$_b$	
dive duration[y]				
< 30 minutes	16 (19.3%)	15 (28.8%)$_a$	1 (3.2%)$_b$	<0.001
30 – 60 minutes	38 (45.8%)	29 (55.8%)$_a$	9 (29.0%)$_b$	
> 60 minutes	29 (34.9%)	8 (15.4%)$_a$	21 (67.7%)$_b$	

Data missing in [x] = 1, [y] = 6 cases. Categorical data presented as numbers (%) and analyzed using Fisher's exact test. Bonferroni correction was utilized when carrying out multiple comparisons. Each subscript letter denotes a subset of categories whose column proportions do not differ from each other at the .05 level.
CMAS, Confédération Mondiale des Activités Subaquatiques; min, minutes; msw, meters sea water; REC, recreational dive; TECH, technical dive

Descriptive statistics are presented as numbers and percentages for categorical variables and as medians and interquartile ranges (IQR) for continuous variables. Categorical data were analyzed using Fisher's exact test (two-tailed) and continuous data using the Mann-Whitney U test. In order to account for multiple comparisons, Bonferroni correction was carried out when necessary.

RESULTS

A total of 89 IEDCS patients were included in the study, with approximately one-sixth (15.6%) of all DCS patients presenting with either isolated (3.3%) or non-isolated (12.3%) cochleovestibular symptoms. Approximately one-third (33.7%) were treated during the first decade, and two-thirds (66.3%) during the latter one. No differences in patient characteristics between the DCS and IEDCS patients were detected; further details are presented in Supplemental Digital Content 1 (SDC 1).

In total, 32 (36.0%) of the IEDCS cases were documented after technical dives and 57 (64.0%) after recreational dives; the characteristics of incident dives are presented in Table 1. Half (56.2%) of the divers were classified as highly qualified, this being the case in 87.5% of technical dives and in 38.6% of recreational dives (p<0.001). While most technical dives (56.3%) were carried out using trimix breathing gases, most recreational dives (71.9%) were carried out using compressed air throughout the dive (p<0.001).

Both depth and duration varied significantly between technical and recreational dives, median (IQR) depth being 45 (33-75) msw for technical and 27 (18-34) msw for recreational dives (p<0.001). The median (IQR) duration of the dives was 80 (56-115) minutes for technical dives and 40 (26-52) minutes for recreational dives (p<0.001), with two-thirds (67.7%) of all technical dives lasting more than 60 minutes.

Predisposing factors of incident dives are presented in Table 2. One or more predisposing factors were identified in 68.8% of technical and in 93.0% of recreational dives (p=0.005). This being said, most of the technical dives could be considered to be predisposing factors in themselves: the median (IQR) depth and duration were 48 (34-100) msw and 103 (63-165) minutes, respectively, in the technical dives without predisposing factors.

Table 2. Predisposing factors of incident dives

	all (n=89)	REC (n=57)	TECH (n=32)	p-value
ongassing-related				
consecutive days of diving	42 (47.2%)	34 (59.6%)	8 (25.0%)	0.002
multiple dives per day	48 (53.9%)	36 (63.2%)	12 (37.5%)	0.027
offgassing-related				
altitude after diving	18 (20.2%)	17 (29.8%)	1 (3.1%)	0.002
uncontrolled ascent	17 (19.1%)	16 (28.1%)	1 (3.1%)	0.004
dehydration	19 (21.3%)	13 (22.8%)	6 (18.8%)	0.790
cold	8 (9.0%)	4 (7.0%)	4 (12.5%)	0.451
other				
elevated intrathoracic pressure	24 (27.0%)	14 (24.6%)	10 (31.3%)	0.619

Categorical data presented as numbers (%) and analyzed using Fisher's exact test. Bonferroni correction was utilized when carrying out multiple comparisons.
REC, recreational dive; TECH, technical dive

The ongassing-related factors were prevalent in both groups, although less so in technical divers: both consecutive days of diving (25.0% vs. 59.6%, p=0.002) and multiple dives per day (37.5% vs. 63.2%, p=0.027) were documented considerably less often in technical than in recreational divers.

Concerning the initial symptoms, a minority of patients were affected by hearing loss (18.0%) or tinnitus (11.2%), while almost all (93.3%) patients experienced vertigo and almost half (41.6%) experienced nausea and vomiting. Isolated cochlear and vestibular symptoms were reported by 6.7% and 80.9%, respectively, whereas the remaining 12.4% reported a combination of symptoms.

Concerning symptoms at examination (i.e., on arrival at the facilities), the cochlear symptoms persisted more or less unaffected while symptoms of vertigo, unsteadiness, and nausea and vomiting were somewhat alleviated in a small proportion of patients (most likely due to first aid procedures such as administration of intravenous fluids and FAO_2). All symptoms were more common and more severe after technical diving, reaching statistical significance in the case of vertigo (p=0.036) and nausea and vomiting (p=0.006). Notably, the right ear was affected in 18 of the 22 patients (81.8%) who were examined sufficiently to determine the affected ear, while only four of 22 patients (18.2%) presented with left-sided symptoms.

Symptoms in other organ systems are also presented. The cases of non-isolated IEDCS comprised three-quarters (78.7%) of all patients, the remaining one-quarter (21.3%) presenting with symptoms of isolated IEDCS. The most common non-cochleovestibular symptoms were osteomyoarticular (49.4%), followed by symptoms consistent with sensorineural (47.2%), cerebral (39.3%), pulmonary (20.2%), and cutaneous (15.7%) involvement. In total, 58.6% of those with non-isolated IEDCS presented with other symptoms associated with the embolization of inert gas bubbles through a right-to-left shunt (i.e., symptoms of cerebral, spinal, or cutaneous involvement) (Table 3).

Treatment protocols and outcomes are presented in Table 4. FAO_2 was utilized by 49.4% of all patients, this being the case in 65.6% of technical and 40.4% of recreational divers (p=0.028). The delay to recompression differed after technical and recreational dives, the median (IQR) delay being 17 (6-24) hours in technical and 24 (7-60) hours in recreational divers (p=0.009), and almost half (39.6%) of all recreational divers being recompressed more than 24 hours after the incident dive. The median (IQR) number of recompressions was two (1-5) in both technical and recreational divers.

Treatment outcomes were similar in both groups: The median (IRQ) iFIS and rFIS scores were 2 (1-3) and 0 (0-1), respectively, in both technical and recreational divers, and no difference in the number of recompressions was recorded. In total, 69.0% of the patients were asymptomatic at discharge and 73.5% of those with follow-up data available (n=49) were asymptomatic at follow-up (Table 4).

Table 3. Symptom development after incident dives

	all (n=89)	REC (n=57)	TECH (n=32)	p-value
SYMPTOMS AT THE INITIAL STAGE				
onset of symptoms				
when descending	1 (1.1%)	1 (1.8%)	0 (0.0%)	0.02
when ascending	6 (6.7%)	2 (3.5%)	4 (12.5%)	
when surfacing	30 (33.7%)	15 (26.3%)$_a$	15 (46.9%)$_b$	
after surfacing	52 (58.4%)	39 (68.4%)$_a$	13 (40.6%)$_b$	
onset of symptoms^x				
< 120 min	59 (68.6%)	32 (58.2%)	27 (87.1%)	0.055
120 – 359 min	7 (8.1%)	6 (10.9%)	1 (3.2%)	
6 – 24 h	14 (16.3%)	12 (21.8%)	2 (6.5%)	
> 24 h	6 (7.0%)	5 (9.1%)	1 (3.2%)	
SYMPTOMS AT THE INITIAL STAGE				
hearing loss	16 (18.0%)	8 (14.0%)	8 (25.0%)	0.25
tinnitus	10 (11.2%)	4 (7.0%)	6 (18.8%)	0.16
vertigo	83 (93.3%)	54 (94.7%)	29 (90.6%)	0.66
nausea & vomiting	37 (41.6%)	20 (35.1%)	17 (53.1%)	0.120
SYMPTOMS / SIGNS AT EXAMINATION				
hearing loss / tinnitus				
no	72 (80.9%)	48 (84.2%)	24 (75.0%)	0.400
yes	17 (19.1%)	9 (15.8%)	8 (25.0%)	
vertigo				
no	12 (13.5%)	8 (14.0%)	4 (12.5%)	0.40
yes (when mobilized)	21 (23.6%)	18 (31.6%)$_a$	3 (9.4%)$_b$	
yes (when immobilized)	56 (62.9%)	31 (54.4%)$_a$	25 (78.1%)$_b$	
unsteadiness				
no	14 (15.7%)	9 (15.8%)	5 (15.6%)	0.13
yes (standing eyes closed)	15 (16.9%)	13 (22.8%)	2 (6.3%)	
yes (standing eyes open)	60 (67.4%)	35 (61.4%)	25 (78.1%)	
nausea and vomiting				
no	52 (58.4%)	37 (64.9%)	15 (46.9%)	0.006
yes (nausea)	22 (24.7%)	16 (28.1%)	6 (18.8%)	
yes (nausea and vomiting)	15 (16.9%)	4 (7.0%)$_a$	11 (34.4%)$_b$	
SYMPTOMS BY ORGAN SYSTEM				
cochleovestibular (isolated)	19 (21.3%)	12 (21.1%)	7 (21.9%)	1.000
cochleovestibular (non-isolated)	70 (78.7%)	45 (78.9%)	25 (78.1%)	1.000
osteomyoarticular	44 (49.4%)	26 (45.6%)	18 (56.3%)	0.38
sensorineural	42 (47.2%)	31 (54.4%)	11 (34.4%)	0.080
pulmonary	18 (20.2%)	10 (17.5%)	8 (25.0%)	0.42
cutaneous	14 (15.7%)	7 (12.3%)	7 (21.9%)	0.24
cerebral	35 (39.3%)	22 (38.6%)	13 (40.9%)	0.85

Data missing in ^{x} = 3 cases. Categorical data presented as numbers (%) and analyzed using Fisher's exact test. Bonferroni correction was utilized when carrying out multiple comparisons. Each subscript letter denotes a subset of categories whose column proportions do not differ from each other at the .05 level.

h=hours; min=minutes; REC=recreational dive; TECH=technical dive

Table 4. Treatment protocols and outcomes after incident dives

	all (n=89)	REC (n=57)	TECH (n=32)	p-value
FIRST AID O_2				
no	45 (50.6%)	34 (59.6%) $_a$	11 (34.4%)$_b$	0.030
yes	44 (49.4%)	23 (40.4%)$_a$	21 (65.6%)$_b$	
DELAY TO RECOMPRESSION^x				
< 4 h	13 (15.7%)	8 (15.1%)	5 (16.7%)	0.020
4 – 12 h	19 (22.9%)	11 (20.8%)	8 (26.7%)	
12 – 24 h	27 (32.5%)	13 (24.5%)$_a$	14 (46.7%)$_b$	
> 24 h	24 (28.9%)	21 (39.6%)$_a$	3 (10.0%)$_b$	
FIRST RECOMPRESSION				
USN5	15 (16.9%)	12 (21.1%)	3 (9.4%)	0.34
USN6	46 (51.7%)	29 (50.9%)	17 (53.1%)	
USN6 Ext	25 (28.1%)	15 (26.3%)	10 (31.3%)	
Other	3 (3.4%)	1 (1.8%)	2 (6.3%)	
NUMBER OF RECOMPRESSIONS				
1	32 (36.0%)	20 (35.1%)	12 (37.5%)	
2	22 (24.7%)	14 (24.6%)	8 (25.0%)	
≥ 3	35 (39.3%)	23 (40.4%)	12 (37.5%)	
TREATMENT SCORES^y				
iFIS				
1	23 (26.4%)	15 (26.8%)	8 (25.8%)	0.17
2	35 (40.2%)	26 (46.4%)	9 (29.0%)	
3	29 (33.3%)	15 (26.8%)	14 (45.2%)	
4	0 (0.0%)	0 (0.0%)	0 (0.0%)	
rFIS				
0	60 (69.0%)	40 (71.4%)	20 (64.5%)	0.59
1	17 (19.5%)	10 (17.9%)	7 (22.6%)	
2	9 (10.3%)	6 (10.7%)	3 (9.7%)	
3	1 (1.1%)	0 (0.0%)	1 (3.2%)	
4	0 (0.0%)	0 (0.0%)	0 (0.0%)	
TREATMENT OUTCOMES				
no symptoms at discharge	60 (69.0%)	40 (71.4%)	20 (64.5%)	0.63
no symptoms at follow-up^z	36 (73.5%)	24 (75.0%)	12 (70.6%)	0.75

Data missing in ^{x} = 6, ^{y} = 2, ^{z} = 40 cases. Categorical data presented as numbers (%) and analyzed using Fisher's exact test. Bonferroni correction was utilized when carrying out multiple comparisons. Each subscript letter denotes a subset of categories whose column proportions do not differ from each other at the .05 level.

h, hours; iFIS, initial functional impairment score; rFIS, residual functional impairment score; REC, recreational dive; TECH, technical dive; USN5, US Navy Table 5; USN6, US Navy Table 6; USN6 Ext, US Navy Table 6 Extended

DISCUSSION

This study provides a detailed description of all IEDCS cases treated at Hyperbaric Center Medioxygen or National Hyperbaric Centre of Turku University Hospital during 1999 – 2018. Previously, the DCS patients treated at these facilities have been estimated to comprise at least 95% of all DCS patients treated in Finland during the time period [16]; considering this and the high level of disability associated with IEDCS, it can be assumed that an even greater proportion of all IEDCS patients is included in the analysis.

Approximately one-sixth (15.6%) of all DCS patients presented with either isolated (3.3%) or non-isolated (12.3%) symptoms of IEDCS and additionally, two-thirds of the patients (66.3% vs. 33.7%) were treated during the latter decade (2009-2018 vs. 1999-2008). This increase in the incidence of IEDCS has already been documented by previous research: While incidences between 2.8% to 10% have been reported in earlier reports [14,17], substantially higher numbers between 22.7% to 33.7% have been reported in more recent publications [13,18,19]. This increase has been shown to be associated with a distinct change in recreational diving practices [18,] more specifically an increase in repetitive diving, reverse-profile diving, and diving to increasing depths. Indeed, some of these changes have also been reported in Finland [16].

The predisposing factors related to inert gas uptake (ongassing) were the most common: Approximately half of the incident dives were precipitated by consecutive days of diving (47.2%), and half by multiple dives per day (53.9%). In total, almost two-thirds (61.8%) of all cases were precipitated by at least one of the ongassing-related factors.

The second most common factor was a rise in intrathoracic pressure (27.0%), resulting from physical exertion in two-thirds and from middle ear equalization difficulties and forceful Valsalva maneuvers in one-third of cases. This rise in intrathoracic pressure has been demonstrated to promote the embolization of inert gas bubbles through an existing (moderate to large) right-to-left shunt [20,21], and the connection between right-to-left shunts and IEDCS has also been repeatedly established [10,11,13,15,19].

The cases with symptoms before surfacing (7.8%) consisted mostly of exceptionally deep dives (>90 msw) with mixed breathing gases, the symptoms appearing immediately (33.7%) or shortly after (58.4%) reaching the surface in most cases. The faster onset of symptoms in technical divers can most likely be attributed to the higher inert gas uptake during the dives.

The distribution of symptoms aligned with previous reports, with only a minority (19.1%) experiencing cochlear and the majority (93.3%) experiencing vestibular symptoms. This has been attributed to a higher tissue volume [22] and a smaller perfusion volume [23,24] in the vestibule compared to the cochlea, leading to an increased inert gas load and therefore to increased local supersaturation. The higher inert gas load most likely explains the more severe symptoms in technical compared to recreational divers as well, due to the higher inert gas uptake during the technical dives.

The laterality of symptoms also aligned with previous reports. In the 22 patients who were examined sufficiently to determine the affected ear 18 (81.8%) showed signs of right-sided involvement while only four (18.2%) showed signs of the left ear being affected. This right-sided susceptibility has been attributed to the preferential embolization of inert gas bubbles into the brachiocephalic artery and from there to the right labyrinthine artery, as opposed to the left subclavian and from there onward to the left labyrinthine artery [12,14,25].

The disparity in FAO_2 utilization between technical and recreational divers (65.6% vs. 40.4%, p=0.028) most likely reflects the better diving education, the better FAO_2 availability, and the more severe cochleovestibular symptoms of technical divers after the incident dives. Correspondingly, the shorter delay to recompression in technical divers most likely reflects the better diving education and the more severe cochleovestibular symptoms after the incident dives.

Concerning the treatment outcomes, approximately two-thirds (69.0%) of the patients had no symptoms at the time of discharge, while one-third (31.0%) were discharged with mild to moderate cochleovestibular symptoms: These included hearing loss and tinnitus in some cases and vestibular disturbances in almost all cases. These comparatively high rates of recovery are most likely explained by the more extensive otoneurological tests carried out in previous publications.

Whereas previous literature suggests that the cochlear function rarely recovers, the vestibular function has a better prognosis [3,4]: Most patients show signs of good clinical recovery at follow-up through visual, proprioceptive, and central vestibular compensation mechanisms, integrating changed peripheral vestibular information from both the damaged and the healthy side. It should be noted that this compensatory information can be challenged underwater, especially in Finnish diving environments which consist largely of sea and lakes with poor visibility, and challenging overhead environments such as abandoned mines and quarries. In these circumstances, sudden vestibular mismatch might quickly result in recurring, incapacitating vestibular symptoms, with serious or possibly even fatal consequences. Therefore, comprehensive otoneurological examinations should be carried out for all (symptomatic and asymptomatic) patients after an IEDCS incident, and careful consideration should be given before deciding on future fitness to dive.

Limitations

The limitations mainly originate from the retrospective design of the study. Due to the coverage of two independent treatment facilities over a relatively long observation period, some missing data was unavoidable, resulting from both differences and temporal development in data collection.

This missing data was particularly noticeable when extracting specific diagnostic information; the data on otoscopic examinations, tuning fork tests, and clinical balance and vestibular examinations were missing in most cases, and right-to-left shunt -testing was largely unavailable during the entire observation period. The missing data was attributable to both insufficient examination and particularly to the insufficient documentation of such examinations, even though the clinical descriptions were in all cases consistent with IEDCS. The examination protocols are currently under review, and detailed instructions on the examination of all IEDCS patients are being developed in our centers.

CONCLUSIONS

This study describes virtually all IEDCS cases in Finland over the 20-year observation period, and it seems that the incidence of IEDCS in Finland is increasing. The most common predisposing factors were related to increased inert gas uptake (ongassing) and the right-to-left shunting of inert gas bubbles (a rise in intrathoracic pressure), the symptoms being predominantly vestibular with a tendency for right-sided lateralization.

The differences between the symptoms in technical and recreational divers (shorter time to symptom onset, more symptoms, more severe symptoms) can be attributed to the higher inert gas intake in technical divers. Conversely, the lack of differences between treatment outcomes can be attributed to the better utilization of FAO_2 (due to better diving education, better FAO_2 availability, and more severe symptoms) and the shorter delay to recompression (due to better diving education and more severe symptoms) in technical divers. In all cases, comprehensive otoneurological examinations should be carried out after an incident of IEDCS, before deciding on future fitness to dive.

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Conflict of interest statement

The authors have declared no conflicts of interest.

Disclaimer

The views expressed in the manuscript are solely those of the authors and do not reflect the official policy or position of the Finnish Defence Forces.

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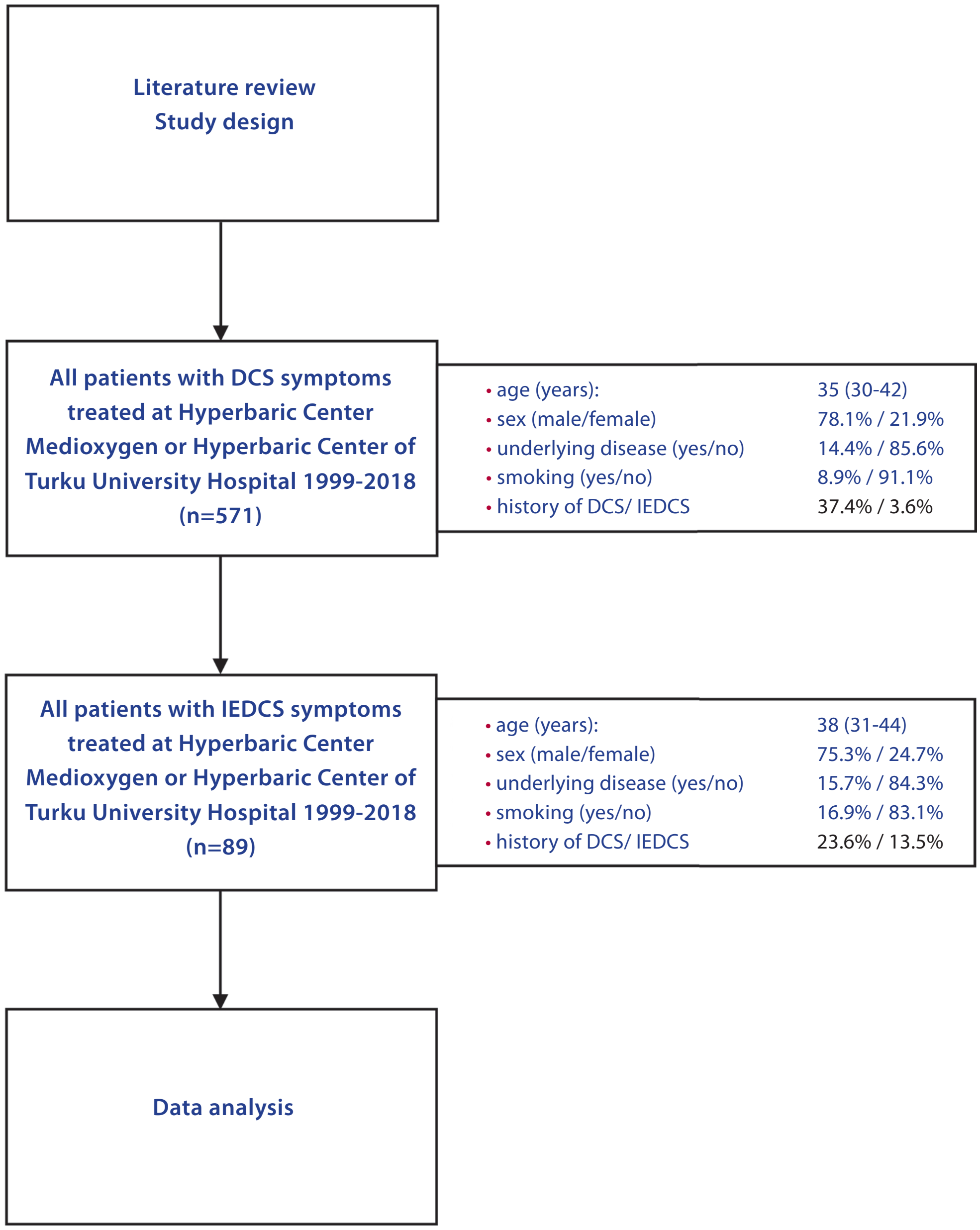
SUPPLEMENTARY INFORMATION

Details of data acquisition and patient demographics



Data presented as percentages for categorical data and as medians and interquartile ranges for continuous data.