Inner ear barotrauma and inner ear decompression sickness: a systematic review on differential diagnostics

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Abstract
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Introduction: Inner ear barotrauma (IEBt) and inner ear decompression sickness (IEDCS) are the two dysbaric inner ear injuries associated with diving. Both conditions manifest as cochleovestibular symptoms, causing difficulties in differential diagnosis and possibly delaying (or leading to inappropriate) treatment.
Methods: This was a systematic review of IEBt and IEDCS cases aiming to define diving and clinical variables that help differentiate these conditions. The search strategy consisted of a preliminary search, followed by a systematic search covering three databases (PubMed, Medline, Scopus). Studies were included when published in English and adequately reporting one or more IEBt or IEDCS patients in diving. Concerns regarding missing and duplicate data were minimised by contacting original authors when necessary.
Results: In total, 25 studies with IEBt patients (n = 183) and 18 studies with IEDCS patients (n = 397) were included. Variables most useful in differentiating between IEBt and IEDCS were dive type (free diving versus scuba diving), dive gas (compressed air versus mixed gas), dive profile (mean depth 13 versus 43 metres of seawater), symptom onset (when descending versus when ascending or surfacing), distribution of cochleovestibular symptoms (vestibular versus cochlear) and absence or presence of other DCS symptoms. Symptoms of difficult middle ear equalisation or findings consistent with middle ear barotrauma could not be reliably assessed in this context, being insufficiently reported in the IEDCS literature.
Conclusions: There are multiple useful variables to help distinguish IEBt from IEDCS. Symptoms of difficult middle ear equalisation or findings consistent with middle ear barotrauma require further study as means of distinguishing IEBt and IEDCS.

Introduction

Inner ear barotrauma (IEBt) and inner ear decompression sickness (IEDCS) are the two dysbaric inner ear injuries associated with diving. Whereas IEBt ultimately results from mechanical damage due to a pressure gradient between the middle and the inner ear, IEDCS results from bubble formation from dissolved gas either within the venous blood with subsequent arterialisation of bubbles and distribution to the labyrinthine artery, or within the membranous labyrinth itself.[1–5] Although the physiology and pathophysiology of IEBt and IEDCS are distinctly different, both conditions may manifest similarly, presenting as symptoms of cochlear (hearing loss, tinnitus) and/or vestibular (vertigo, nausea and vomiting) involvement.[1,2] These similarities can cause difficulties in differentiating between IEBt and IEDCS, possibly delaying (or leading to inappropriate) treatment.

These difficulties in differential diagnosis have been repeatedly discussed in previous literature,[1,2] and progress in differentiating between the two conditions has been made. Recently, based on a review of the relevant literature, the '*HOOYAH tool*' has been created to assist in the differentiating between IEBt and IEDCS. The tool consists of: 1) H – hard to clear; 2) O – onset of symptoms; 3) O – otoscopic exam; 4) Y – your dive profile; 5) A – additional symptoms and 6) H – hearing.[6] Although the tool is convenient, there are some limitations in the literature review on which it is based, including the inclusion of non-original studies (e.g., review articles), the inclusion of studies with neither IEBt nor IEDCS patients (e.g., studies examining otoacoustic emission testing or studies examining diving-related injuries in general), and the inclusion of patients with inner ear injuries resulting from non-diving related activities (e.g., inner ear injuries after head trauma). In addition, the review of the literature primarily focused on IEBt, with significantly less attention given to IEDCS characteristics.[6]

Taking this into account, a systematic review with differently refined inclusion and exclusion criteria might provide additional information on the subject. Therefore, we carried out a systematic literature review to both elucidate and elaborate the differentiation between IEBt and IEDCS.

Methods

SEARCH STRATEGY

A preliminary literature search was carried out (search date 10 December 2020) in the PubMed database to identify all appropriate index terms and keywords for the final systematic literature search. This consisted of carrying out the preliminary search (index terms "*Diving*" AND "*Inner Ear*"), obtaining the preliminary search results (n = 228), and scanning these results (including the titles, abstracts, index terms, and key words of the 'similar articles' and 'cited articles') for all appropriate index terms and key words. Details of the preliminary search are presented in Appendix 1.

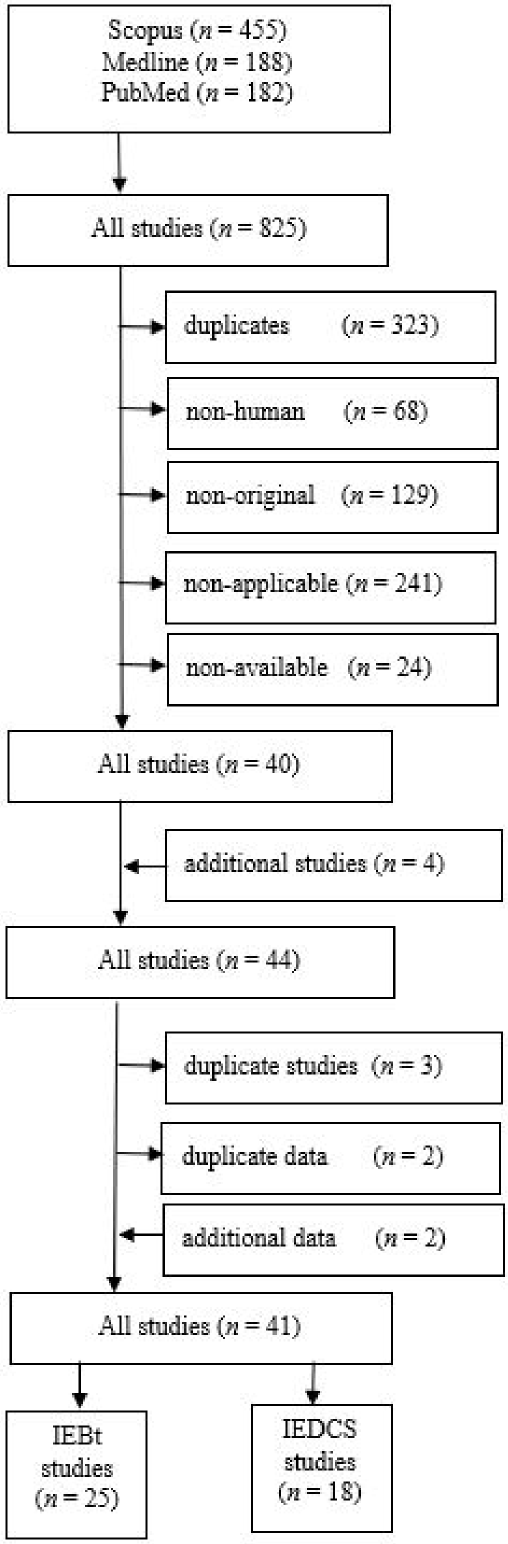
A systematic literature search was carried out (search date 10 December 2020, confirmatory search date 26 April 2021) in the PubMed, Medline, and Scopus databases, utilising all the index terms and key words identified in the preliminary search, and limiting the search to studies published in English. Details of the systematic search are presented in Appendix 2.

STUDY SELECTION STRATEGY

A flow chart of the study selection process is presented in Figure 1. The studies were included when adequately reporting at least one or more IEBt or IEDCS patients in connection to diving activity, resulting in 40 included studies after the exclusion of all duplicate, non-human (i.e., animal or laboratory studies), non-original (i.e., review articles, commentaries, letters, and editorials), non-applicable (i.e., no applicable patients) and non-available studies (i.e., no full text available). Furthermore, four more additional studies, extracted from the references or the references of references, were included, resulting in 44 included studies.

Missing data were minimised by sending out data requests to all corresponding authors (n = 8) of studies with large ($n \geq 30$) sample sizes, resulting in additional information on two studies. Conversely, duplicate data were minimised by sending out data requests to the corresponding authors when necessary, resulting in the exclusion of three studies and the deletion of some of the patients in two studies. A list of the final 41 studies that were included is presented in Appendix 3.

Figure 1
A flow chart of the study selection process; the total number of IEBt (n = 25) and IEDCS (n = 18) studies exceeds the total number of all studies (n = 41) as two studies included both IEBt and IEDCS patients. IEBt – inner ear barotrauma; IEDCS – inner ear decompression sickness



Footnote: * Appendix 1–3 are available on DHM Journal's website: https://www.dhmjournal.com/index.php/journals?id=288

DATA EXTRACTION STRATEGY

The data extracted from the final 41 studies included the study design, the study setting, and the number and general characteristics of all applicable patients. In addition, data on the relevant dive details were extracted, including the depth and duration of the incident dives, the breathing gases used, and the predisposing factors reported in connection to the incident dives; defined as middle ear equalisation difficulties in IEBt patients and any of the generally established DCS risk factors (i.e., consecutive days of diving, multiple dives per day, altitude exposure after the incident dive, uncontrolled ascent from the dive, dehydration or feeling cold during the dive, physical exertion during or after the dive, obesity) in IEDCS patients.

Data on the development, distribution and laterality of cochleovestibular symptoms were extracted, as well as data regarding symptoms attributable to other DCS manifestations. Data on the relevant findings, the treatment delay, the treatment(s) received and the outcomes at discharge and at follow-up were also extracted, when available. Finally, data regarding the continuation of diving activity were also extracted.

STATISTICAL ANALYSIS

All statistical analyses were performed using SPSS Statistics for Windows, version 27.0, released 2020 (IBM Corp, Armonk, NY, USA). A two-tailed *P*-value of < 0.05 was interpreted to indicate statistical significance.

The data are presented as numbers and percentages in the case of categorical variables (analysed using Fisher's exact test) and as means and ranges in the case of continuous variables (analysed using independent samples *t*-test). The Bonferroni correction was applied to adjust for multiple comparisons.

Results

OVERVIEW OF STUDIES

The 25 IEBt studies included 183 patients and were published between 1970 and 2016.[7–31] Approximately half (44.3%) of the patients were from studies published between 1970 and 2000, the other half (55.7%) from studies published between 2001 and 2016. All studies were case reports, case series or retrospective chart reviews; with the diagnosis in most cases verified via pure tone audiometry,

Table 1

Characteristics of incident dives; categorical data are presented as *n* (%) and continuous data are presented as mean (range). Triplets of superscripted numbers denote the numbers of observations: total, IEBt, IEDCS (e.g., data on dive type reported in 570 patients, 173 IEBt patients, 397 IEDCS patients). Each subscript letter denotes a subset of categories whose column proportions do not differ significantly from each other at the 0.05 level. IEBt – inner ear barotrauma; IEDCS – inner ear decompression sickness; min – minutes; msw – metres of sea water

Variable	All (*n* = 580)	IEBt (*n* = 183)	IEDCS (*n* = 397)	*P*
Dive type$^{570, 173, 397}$				
Scuba diving	536 (94.0)	140 (80.9)$_a$	396 (99.7)$_b$	< 0.001
Free diving	32 (5.6)	31 (17.9)$_a$	1 (0.3)$_b$	
Other	2 (0.4)	2 (1.2)$_a$	0$_b$	
Dive gas$^{450, 59, 391}$				
Air	362 (80.4)	59 (100.0)$_a$	303 (77.5)$_b$	< 0.001
Nitrox	23 (5.1)	0	23 (5.9)	
Heliox	22 (4.9)	0	22 (5.6)	
Trimix	43 (9.6)	0$_a$	43 (11.0)$_b$	
Dive depth (msw)$^{332, 51, 281}$				
Mean	38.0	13.0	42.5	< 0.001
Range	1–200	1–49	9–200	
Dive duration (min)$^{179, 6, 173}$				
Mean	38.7	25.2	39.2	0.012
Range	5–180	5–40	5–180	
Predisposing factors				
for IEBt$^{303, 137, 164}$	124 (40.9)	118 (86.1)$_a$	6 (3.7)$_b$	< 0.001
for IEDCS$^{534, 137, 397}$	211 (39.5)	0$_a$	211 (53.1)$_b$	

Table 2

Symptom and findings after incident dives; categorical data are presented as *n* (%) and continuous data are presented as mean (range). Triplets of superscripted numbers denote numbers of observations: total, IEBt, IEDCS (e.g., data on symptom onset reported in 489 patients, 92 IEBt patients, 397 IEDCS patients). Each subscript letter denotes a subset of categories whose column proportions do not differ significantly from each other at the 0.05 level. HL – hearing loss; IEBt – inner ear barotrauma; IEDCS – inner ear decompression sickness; MEBt – middle ear barotrauma

Variable	All (n = 580)	IEBt (n = 183)	IEDCS (n = 397)	P
Onset$^{489, 92, 397}$				
When descending	17 (3.5)	17 (18.5)$_a$	0_b	< 0.001
When ascending	33 (6.7)	3 (3.3)	30 (7.6)	
When surfacing	57 (11.7)	30 (32.6)$_a$	27 (6.8)$_b$	
After surfacing	382 (78.1)	42 (45.7)$_a$	340 (85.6)$_b$	
Onset delay (hours)$^{347, 7, 340}$				
Mean	0.9	25	0.4	0.010
Range	0–72	1.5–72	0–16	
Inner ear symptoms$^{580, 183, 397}$				
Cochlear	303 (52.2)	172 (94.0)	131 (33.0)	< 0.001
Vestibular	446 (76.9)	82 (44.8)	364 (91.7)	< 0.001
Cochlear symptoms$^{465, 183, 282}$				
Hearing loss	232 (49.9)	152 (83.1)	80 (28.4)	< 0.001
Tinnitus	169 (36.3)	123 (67.6)	46 (16.3)	< 0.001
Vestibular symptoms				
Vertigo$^{582, 183, 397}$	446 (76.9)	82 (44.8)	364 (91.7)	< 0.001
Nausea and vomiting$^{313, 98, 215}$	177 (56.5)	13 (13.3)	164 (76.3)	< 0.001
Other DCS symptoms$^{582, 183, 397}$				
No	478 (82.1)	181 (98.9)	297 (74.8)	< 0.001
Yes	102 (17.9)	2 (1.1)	100 (25.2)	
Laterality of symptoms$^{382, 86, 296}$				
Right-sided	230 (60.2)	35 (40.7)$_a$	195 (65.9)$_b$	< 0.001
Left-sided	147 (38.5)	48 (55.8)$_a$	99 (33.4)$_b$	
Both-sided	5 (1.3)	3 (3.5)$_a$	2 (0.7)$_b$	
Otological findings				
Sensorineural HL$^{505, 179, 326}$	230 (45.5)	155 (86.6)	75 (23.0)	< 0.001
Nystagmus$^{322, 84, 238}$	182 (56.5)	24 (28.6)	158 (66.4)	< 0.001
MEBt$^{267, 118, 149}$	65 (24.3)	57 (48.3)	8 (5.4)	< 0.001
Other findings				
Right-to-left shunt$^{255, 3, 252}$	176 (69.0)	0	176 (69.8)	0.029

electronystagmography and/or surgical exploration of the tympanic cavity (i.e., exploratory tympanotomy).

The 18 IEDCS studies included 397 patients and were published between 1976 and 2019.[12,18,32–47] A minority of the patients (9.1%) were from studies published between 1976 and 2000, and the majority (90.9%) from studies published between 2001 and 2019. All studies were case reports, case series or retrospective chart reviews; the diagnosis in many cases verified via pure tone audiometry and/or electronystagmography. Quantitative synthesis of the studies is presented in Tables 1, 2 and 3, and described below.

COMPARISON OF INCIDENT DIVES

Characteristics of incident dives are presented in Table 1. A minority of IEBt cases appeared after free diving (17.9%), while the majority of both IEBt (80.9%) and IEDCS (99.7%) cases appeared in connection to scuba diving. The breathing gas used during the scuba dives was compressed air in all (100.0%) dives preceding IEBt and in three quarters (77.5%) of the dives preceding IEDCS (P < 0.001). The remaining quarter of IEDCS cases appeared after the use of nitrox (5.9%), heliox (5.6%), or trimix (11.0%). The mean depth and duration of the dives were 13 metres of

Table 3

Treatment protocols and outcomes after incident dives; categorical data are presented as *n* (%) and continuous data are presented as mean (range). Triplets of superscripted numbers denote numbers of observations: total, IEBt, IEDCS (e.g., data on treatment delay reported in 402 patients, 72 IEBt patients, 331 IEDCS patients). Each subscript letter denotes a subset of categories whose column proportions do not differ significantly from each other at the 0.05 level. HBOT – hyperbaric oxygen treatment; IEBt – inner ear barotrauma; IEDCS – inner ear decompression sickness

Variable	All (*n* = 580)	IEBt (*n* = 183)	IEDCS (*n* = 397)	*P*
Delay to treatment (hours)[403, 72, 331]				
Mean	39.1	189	6.6	< 0.001
Range	0–1176	0–1176	0–336	
Modality of treatment[558, 161, 397]				
Conservative	127 (22.8)	108 (67.1)$_a$	19 (4.8)$_b$	< 0.001
Surgical	53 (9.5)	53 (32.9)$_a$	0 (0.0)$_b$	
HBOT	385 (69.0)	7 (4.4)$_a$	378 (95.2)$_b$	
Number of HBOT[342, 7, 335]				
Mean	2.9	1.0	2.9	< 0.001
Range	1–26	1–1	1–26	
Full recovery				
At discharge[387, 80, 307]	125 (32.3)	13 (16.2)	112 (36.5)	< 0.001
At follow-up[323, 83, 240]	174 (53.9)	27 (32.5)	147 (61.3)	< 0.001
Continuation of diving[157, 31, 126]				
Yes	106 (67.5)	27 (87.1)	79 (62.7)	0.010
No	51 (32.5)	4 (12.9)	47 (37.3)	

seawater (msw) and 25 min preceding IEBt and 43 msw and 39 min preceding IEDCS ($P < 0.001$ for depth and $P = 0.012$ for duration, respectively).

While predisposing factors for DCS were documented in approximately half (53.1%) of the IEDCS cases, a predisposing factor for IEBt (i.e., middle ear equalisation difficulties) was documented in the vast majority (86.1%) of IEBt patients.

COMPARISON OF SYMPTOMS AND FINDINGS

Symptoms and findings after the incident dives are presented in Table 2. In IEBt patients, the symptoms appeared in all stages of the dive; either when descending (18.5%), when ascending (3.3%), when surfacing (32.6%) or after surfacing (45.7%). Conversely, the symptoms of IEDCS appeared when ascending (7.6%) or when surfacing (6.8%) in only a minority of cases, developing in most cases shortly after reaching the surface (85.6%). The mean delay to onset of symptoms was 0.4 h in IEDCS patients. Among 42 IEBt patients with onset after surfacing, latency was only reported for seven and the mean 25 hour latency may be anomalous.

The symptoms of IEBt patients were cochlear in almost all cases: a total of 83.1% reported hearing loss and 67.6% reported tinnitus, whereas only 44.8% reported vertigo. In contrast, the symptoms of IEDCS patients were predominantly vestibular, with 91.7% reporting vertigo while only 28.4% reported hearing loss and only 16.3% reported tinnitus. Symptoms of other DCI manifestations affected 25.2% of IEDCS and 1.1% of IEBt patients ($P < 0.001$).

The symptoms of IEBt patients had a slight tendency for left-sided lateralisation (55.8% versus 40.7%, $P = 0.047$) while the symptoms of IEDCS patients were predominantly right-sided (65.9% versus 33.4%, $P < 0.001$). Whereas approximately half (48.3%) of the IEBt patients presented with middle ear barotrauma, this was the case in only a few (5.4%) IEDCS patients ($P < 0.001$).

COMPARISON OF TREATMENT PROTOCOLS AND OUTCOMES

Treatment protocols and outcomes are presented in Table 3. The mean delay to treatment was 189 h in IEBt and 7 h in IEDCS patients ($P < 0.001$). Approximately two thirds (67.1%) of IEBt patients were treated conservatively (bed rest with the head elevated, pharmacological management, daily audiometric monitoring) and the remaining one third (32.9%) underwent surgery (exploratory tympanotomy or an injected intratympanic blood patch). Seven IEBt patients (4.4%) were recompressed before the appropriate treatment was instituted. This resulted in no worsening of symptoms in six patients (no data in one patient). Almost all IEDCS patients (95.2%) were recompressed (mean number of recompressions 2.9) but a small minority (4.8%) were not; the reason for this was unspecified in most (14 of 19) cases.

Although infrequently reported, recovery from the inner ear insult seemed less frequent in IEBt than in IEDCS patients; complete recovery was less frequent both at discharge (16.2% versus 36.5%, $P < 0.001$) and at follow up (32.5% versus 61.3%, $P < 0.001$) after IEBt. In contrast, a return to diving was reported more often after IEBt than after IEDCS (87.1% versus 62.7%, $P = 0.010$).

Discussion

AGREEMENT WITH PREVIOUS LITERATURE

This is the first systematic literature review specifically examining the differential diagnosis between IEBt and IEDCS in the context of diving, and the results largely aligned with previous literature. The IEBt cases appeared after both free and scuba diving, while conversely, the IEDCS cases appeared almost exclusively (99.7%) after scuba diving. Furthermore, while all scuba dives (100%) preceding IEBt were carried out using compressed air as the breathing gas, some IEDCS cases appeared after the use of mixed breathing gases (22.5%). This may be utilised in differentiating between IEBt and IEDCS in the future.

The depth and duration of the dives were indeed markedly different between IEBt and IEDCS patients: the mean depth and duration of the incident dive was 13 msw and 25 min preceding IEBt and 42 msw and 39 min preceding IEDCS. This being said, these data were not reported in a large proportion of patients (data on dive depth missing in 132 IEBt and 116 IEDCS patients; data on dive duration missing in 177 IEBt and 224 IEDCS patients), rendering the findings less reliable. Overall, the data suggest that knowledge of the dive profile can be utilised to guide differential diagnosis between IEBt and IEDCS (as proposed by the HOOYAH tool).[6]

Concerning the symptoms, those of the IEBt patients potentially appeared in all stages of the dive. In contrast, the symptoms of IEDCS patients never appeared when descending and appeared in only a minority of cases (i.e., in connection to technical diving with mixed breathing gases) when ascending or immediately when reaching the surface. These findings suggest that in some cases, the onset of symptoms can be a determining factor in differentiating IEBt from IEDCS.

The symptoms were predominantly cochlear in IEBt patients (94.0% with cochlear and 44.8% with vestibular symptoms) and predominantly vestibular in IEDCS patients (91.7% with vestibular and 33.0% with cochlear symptoms). These findings are at best suggestive of the underlying condition when differentiating between IEBt and IEDCS, whereas the presence of other DCI manifestations seem to strongly point towards IEDCS. Overall, the findings suggest that both the onset and distribution (cochlear versus vestibular, isolated versus non-isolated) of the symptoms can contribute to differentiating between IEBt and IEDCS (as proposed by the HOOYAH tool).[6] A summary of the differential diagnostic process between IEBt and IEDCS is presented in Figure 2.

It is worth noting that despite the difficulties in differential diagnosis, the great majority of patients appeared to be diagnosed correctly: only seven IEBt patients (4.4%) were misdiagnosed and recompressed before receiving the appropriate treatment, and no worsening of symptoms was reported in six of these seven patients (no data in one patient). Correspondingly, a total of three IEDCS patients (0.8%) were not recompressed due to diagnostic difficulties, while another two (0.5%) were not recompressed due to the long treatment delay (no data on the reason in 14 patients). This suggests that although most patients are diagnosed correctly, there is a chance of a misdiagnosis in both directions.

DISAGREEMENTS WITH PREVIOUS LITERATURE

Although most of the findings aligned with the guidelines proposed by the HOOYAH tool, this was not the case regarding middle ear equalisation difficulties or middle ear barotrauma. While our results certainly indicate that middle ear equalisation difficulties are a predisposing factor for IEBt but not for IEDCS (86.1% versus 3.7%), a look at the relevant literature suggests that the matter is more complicated.

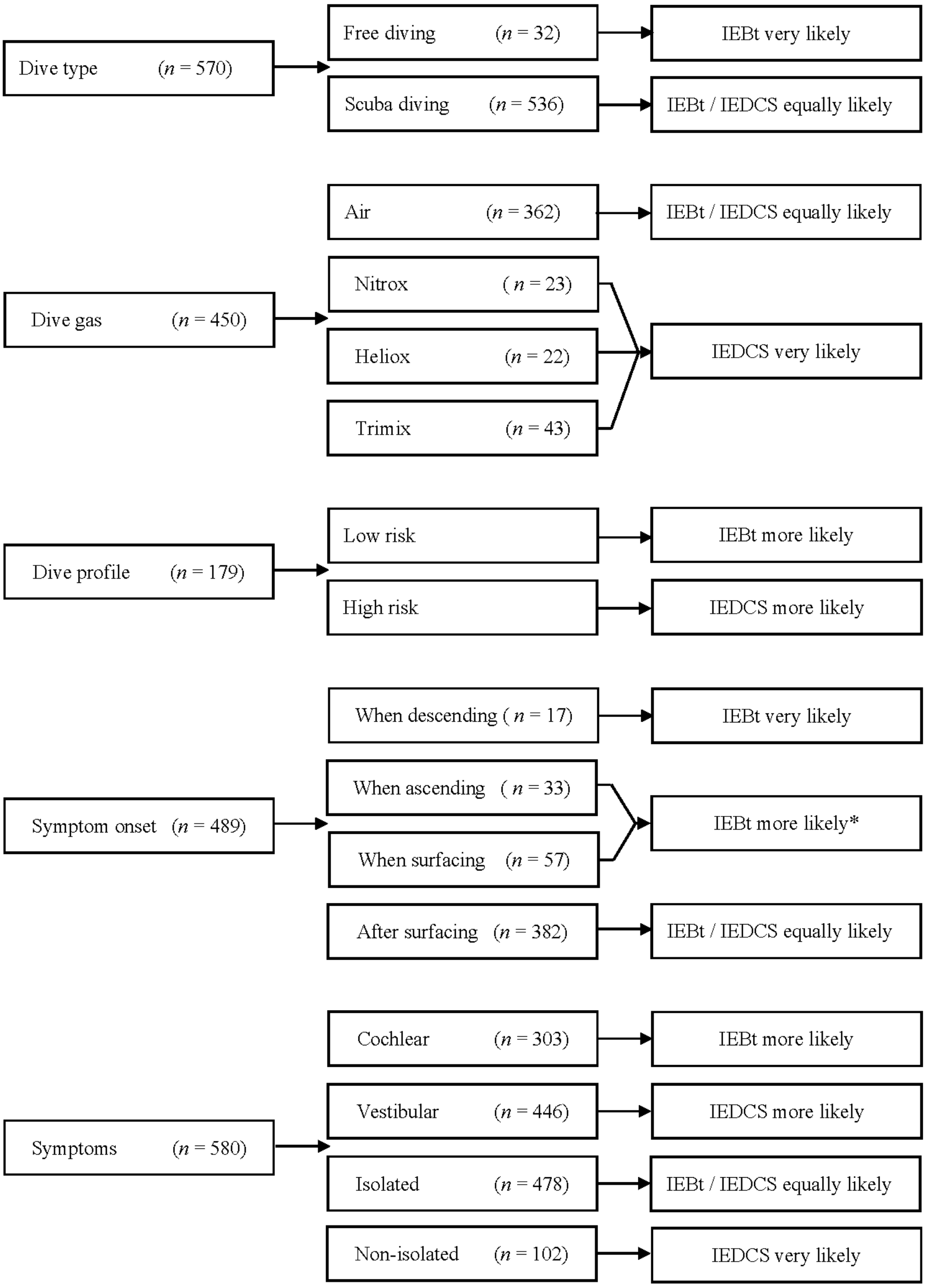
While the connection from middle ear equalisation difficulties and forceful Valsalva manoeuvres to IEBt has been thoroughly discussed and documented in the relevant literature,[1,2] such a connection to IEDCS has never been examined or established. However, forceful Valsalva manoeuvres provoke intrathoracic pressure changes that could promote the passage of venous inert gas bubbles through a (moderate to large) right-to-left shunt.[48,49] Moreover, the connection between right-to-left shunts and IEDCS has been thoroughly established in several publications.[41,43,50–52] Therefore it should be appreciated that if there are inert gas bubbles present in the venous blood (e.g., at the start of a repetitive dive) middle ear equalisation difficulties are not just a predisposing factor for IEBt but could, under such circumstances, predispose to IEDCS as well.

Taking this into account, there is a shortage of data in the relevant literature connecting middle ear equalisation difficulties with IEDCS. This can be explained by a multitude of factors.

Firstly, patients with middle ear equalisation difficulties (or findings consistent with middle ear barotrauma) are routinely excluded from IEDCS studies. Although the practice is in itself certainly justified (so that no IEBt patients are inadvertently included in the studies), it does lead to a slight distortion of the literature, and IEDCS patients with middle ear equalisation difficulties end up being insufficiently acknowledged in the literature. Importantly, considering that patients with middle ear equalisation difficulties (or findings consistent with middle ear barotrauma) were excluded from

Figure 2

A summary of the differential diagnostic process between IEBt and IEDCS; the phrase '*more likely*' is adopted in the case of a substantial polarisation between IEBt and IEDCS patients. The phrase '*very likely*' is adopted in the case of a ≈ 99% polarisation between IEBt and IEDCS patients. * IEBt more likely but IEDCS more likely when scuba diving with mixed breathing gases. IEBt – inner ear barotrauma; IEDCS – inner ear decompression sickness



the IEDCS studies from which the HOOYAH tool originates from, such findings cannot be the basis for differentiating between IEBt and IEDCS in the algorithm.

Secondly, even when patients with middle ear equalisation difficulties are not excluded from the IEDCS studies, the presence or absence of middle ear equalisation difficulties in IEDCS patients is rarely reported in the original publications (for example, all the patients with middle ear equalisation difficulties in this study were identified by contacting the authors and asking directly about any such difficulties). This would suggest that the true number of IEDCS patients with middle ear equalisation difficulties is greater than that described in the relevant literature.

Thirdly, even when the patients are not excluded, and even when the middle ear equalisation difficulties are documented, the patients themselves tend to insufficiently report their possible difficulties in middle ear equalisation.[25] That middle ear equalisation difficulties will often be missed without a careful and complete interrogation of patients has been documented previously.[25] This means that even when the patients are not excluded, and even when the middle ear equalisation difficulties are systematically recorded, the patients themselves have to be elaborately questioned to reveal any difficulties with middle ear equalisation during the incident dive.

Overall, this means that contrary to the current guidelines provided by the HOOYAH tool, symptoms of poor middle ear equalisation or findings consistent with middle ear barotrauma may not be reliable in the differentiating between IEBt and IEDCS in all circumstances, for example, when there are venous inert gas bubbles present at the start of a repetitive dive. Although it is possible that these could be useful tools in differentiating between the conditions, such inferences cannot be made from the current literature: therefore these variables should be interpreted with caution when trying to differentiate between IEBt and IEDCS.

STRENGTHS AND LIMITATIONS

The main strength of the study is its overall scope. The results can be considered fairly representative of both conditions as the systematic literature review included all original publications with any IEBt or IEDCS patients, including both small case reports and case series as well as retrospective chart reviews with larger sample sizes (with additional data requests sent to the authors of large studies). Although this can be argued to make the study the most comprehensive review of inner ear disorders in diving published to date, it still remains subject to several limitations.

Firstly, the missing data resulting from the exclusion of studies based on language (studies not published in English) and availability (studies with no full text available) limits the generalisability of our findings. Secondly, the missing patient data resulting from unsystematic reporting (e.g., data on dive depth and duration in IEBt patients, see above) limits the reliability of some of the findings. This could (and should) be mitigated by a more systematic approach to data collection and reporting in the future, whenever possible.

Conclusion

This is the first systematic literature review specifically examining the differential diagnostics between IEBt and IEDCS in the context of diving. The data suggest that the variables most useful in differentiating between IEBt and IEDCS are dive type (freediving versus scuba diving), dive gas (compressed air versus mixed breathing gases), dive profile (mean depth 13 msw versus 43 msw), and the onset (when descending versus when ascending or surfacing) and distribution of cochleovestibular symptoms (vestibular versus cochlear, isolated versus non-isolated). Symptoms of poor middle ear equalisation or findings consistent with middle ear barotrauma could not be reliably assessed as a means of differentiating between IEBt and IEDCS, being insufficiently reported in the relevant literature. These variables should be interpreted with caution when differentiating between IEBt and IEDCS, and future research should focus on examining them in both IEBt and IEDCS patients before a guideline regarding their utilisation can be formulated.

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Appendix 1
Details of the preliminary literature search
Appendix 2
Details of the systematic literature search
Appendix 3
Publications included in the final systematic review