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**MAIN ARTICLE**

# Hyperbaric oxygen therapy for sudden sensorineural hearing loss in divers

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## Abstract

*Objective*: Sudden sensorineural hearing loss in divers may be caused by either inner-ear barotrauma or inner-ear decompression sickness. There is no consensus on the best treatment option. This study aimed to evaluate the therapeutic value of hyperbaric oxygen therapy for sudden sensorineural hearing loss in divers.

*Method*: A literature review and three cases of divers with sudden sensorineural hearing loss treated with hyperbaric oxygen therapy are presented.

*Results*: Hyperbaric oxygen therapy resulted in hearing improvement in 80 per cent of patients: 39 per cent had hearing improvement and 41 per cent had full recovery.

*Conclusion*: Hyperbaric oxygen therapy improved hearing in divers with sudden sensorineural hearing loss.

**Key words:** Hearing Loss, Sudden; Hearing Loss, Sensorineural; Hyperbaric Oxygenation

## Introduction

Sudden sensorineural hearing loss (SNHL) is acute hearing loss that develops within 72 hours.[1–3] It is defined as hearing loss of at least 30 dB affecting three or more contiguous frequencies.[1–3] Physical examination of the external auditory canal and tympanic membrane shows no abnormalities.[1,3] The incidence rate of sudden SNHL is 2–20 cases per 100 000 people per year,[2–5] but no aetiological explanation can be found in 90 per cent of cases.[1,5] Hypotheses on the aetiology of sudden SNHL in the general population include viral, (micro)vascular and autoimmune causes, as well as Ménière's disease.[5–8] Sudden SNHL amongst divers is believed to have a different pathophysiological origin: two frequently reported mechanisms are inner-ear barotrauma and inner-ear decompression sickness.

Boyle's Law states that volume of an airspace is inversely proportional to ambient pressure, and inner-ear barotrauma is a consequence of this relationship.[9,10] Ambient pressure rises during diving, resulting in a decreased air volume in the middle-ear cavity. To equalise pressure in the middle ear, additional volume needs to be added through the Eustachian tube by middle-ear clearing techniques (such as the Valsalva manoeuvre).[11] Middle-ear clearing can result in sudden pressure changes which displace the tympanic membrane and ossicular chain.[8,9] Since the perilymph and endolymph are incompressible, the pressure change is transmitted to other structures such as the labyrinthine membranes and windows.[8,9,12] This is thought to result in rupture of the round or oval window, intralabyrinthine membrane tears or cochlear haemorrhage.[9,11–14] Middle-ear clearing techniques can also cause a sudden rise in cerebrospinal fluid pressure, which can be transmitted through the cochlear aqueduct and/or vestibular aqueduct to the perilymph of the cochlea.[8,9,15]

Inner-ear decompression sickness results from bubble formation from dissolved inert gas during or after a dive.[7,16–19] During a descent, inert gases dissolve in the blood according to Henry's Law, which states that the amount of dissolved gas is directly proportional to ambient pressure.[16,20,21] During ascent, a reverse reaction takes place and inert gas can form bubbles.[16,20] Bubbles travelling to the labyrinthine or cochlear artery can result in sudden SNHL by blocking arterial vessels, resulting in ischaemia.[19] It is hypothesised that nitrogen bubbles can result in more damage to the inner ear by stimulating inflammation and activating the coagulation cascade.[22] Inner-ear barotrauma and inner-ear decompression sickness can present with isolated sudden SNHL, but can also be accompanied by tinnitus, vertigo, nausea, vomiting and nystagmus.[6,11,23,24]

There is no consensus on the best treatment option for sudden SNHL in either the general population or in divers. Some of the most frequently used treatments

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are corticosteroids, antivirals, vasodilators and vasoactive substances.[2,25–27] These treatment options have all been assessed by Cochrane Reviews; however, none had additional therapeutic value compared with either placebo or no treatment.[25–27] Hyperbaric oxygen therapy could provide an alternative treatment option. Hyperbaric oxygen therapy involves administering 100 per cent oxygen at pressures greater than 100 kPa to increase oxygen levels within hypoxic inner-ear structures and decrease both nitrogen levels and bubble diameter in the blood.[2,5,28] Hyperbaric oxygen therapy increases the partial pressure of oxygen within blood and capillaries,[2] which stimulates oxygen diffusion from the capillaries into the surrounding tissue, including hypoxic parts of the cochlea.[5] Secondly, it causes nitrogen bubble dissolution in the labyrinthine and cochlear artery, in accordance with Henry's Law.[19,21] As a result, increased perfusion to the inner ear stimulates cell repair.[2,5] In addition, research shows that hyperbaric oxygen therapy inhibits blood coagulation and pro-inflammatory cytokine production.[5] Hyperbaric oxygen therapy may therefore stimulate hearing recovery in divers with sudden SNHL due to inner-ear barotrauma or inner-ear decompression sickness. This study aimed to evaluate the therapeutic value of hyperbaric oxygen therapy in divers with sudden SNHL.

## Materials and methods

### *Data selection*

A retrospective analysis was undertaken of three divers with sudden SNHL who were treated with hyperbaric oxygen therapy in two hyperbaric oxygen treatment facilities (Den Helder and Sneek, the Netherlands). These patients were treated between January 2013 and October 2015, and all gave written, informed consent. In addition, all published case reports of divers with sudden SNHL and treated with hyperbaric oxygen therapy were assessed and incorporated into a database. An electronic search of the PubMed, Embase, Cochrane Library, Rubicon Research Repository and Gesellschaft für Tauch-und Überdruckmedizin databases was performed on 10 October 2015 (Figure 1). Hand-searching of literature in the Diving Medical Center library was also conducted. Cases were included if the following three criteria were met: (1) sudden SNHL developed during, or within 72 hours, of a dive (defined as submerging oneself under water for recreational or professional purpose using self-contained underwater breathing apparatus or surface-supplied diving gear; breath-hold and free diving were not included); (2) the patient was treated with hyperbaric oxygen therapy; and (3) outcome was evaluated by audiological testing after the last therapy session. Duplicate case reports were removed by comparing diver and dive characteristics. The following data were collected for all patients: age, sex, maximum diving depth, diving time, diving gas, extent of hearing loss, presence of vestibular symptoms, time between dive and symptom onset, time between symptom onset and hyperbaric oxygen therapy, hyperbaric oxygen treatment table, number of hyperbaric oxygen therapy sessions, additional corticosteroid treatment, follow up, diagnosis, and outcome. Hearing loss was reported as the high Fletcher index (mean hearing loss at 1, 2 and 4 kHz), if available, or as hearing loss determined by the case report.

### *Statistical analysis*

Statistical analysis was performed using IBM SPSS Statistics for Windows software version 21.0 (Armonk, New York, USA) and GraphPad Quickcalcs (http://www.graphpad.com/quickcalcs/). Nominal data were analysed using two-tailed Fisher's exact tests and continuous, non-parametric data were analysed using two-tailed Mann–Whitney U-test. For nominal data, statistical significance was set at a $p$ value of less than 0.05. Owing to the large sample size ($n > 20$) $z$ scores were used for Mann–Whitney U-tests and statistical significance was set at a $z$ score of less than $-1.96$ or more than 1.96. The statistical significance of differences in specific characteristics between responders and non-responders was evaluated if the proportion of missing data was smaller than 20 per cent.

## Results

### *Case study 1*

A 43-year-old Navy diver attended a 5-day diving course and developed a sensation of fullness of the left ear. On the fifth day of the course, he noticed hearing loss affecting the left ear after a deep dive. During the dive, no clearing difficulties were encountered. He did not suffer from tinnitus, dizziness or nausea. Pure tone audiometry 3 days later showed left-sided perceptive hearing loss with a mean loss of 70 dB at all frequencies (low Fletcher index = 72 dB, high Fletcher index = 72 dB). Magnetic resonance imaging showed no abnormalities of the middle and inner ear. The patient was treated with prednisone for 4 days (80, 60, 40 and 20 mg) and 10 daily hyperbaric oxygen therapy sessions (250 kPa × 75 minutes) on weekdays. Pure tone audiometry five days after the last hyperbaric oxygen session revealed full hearing recovery. Audiometric analysis 11 months later showed similar results.

### *Case study 2*

A 29-year-old Navy diver developed sudden hearing loss 15 minutes after a helium–oxygen dive. The diving profile was a maximum diving depth of 81 m, a diving time of 125 minutes and a bottom time of 20 minutes. Standard decompression schedules were used. He suffered no middle-ear clearing difficulties or pain during diving but did experience fullness of

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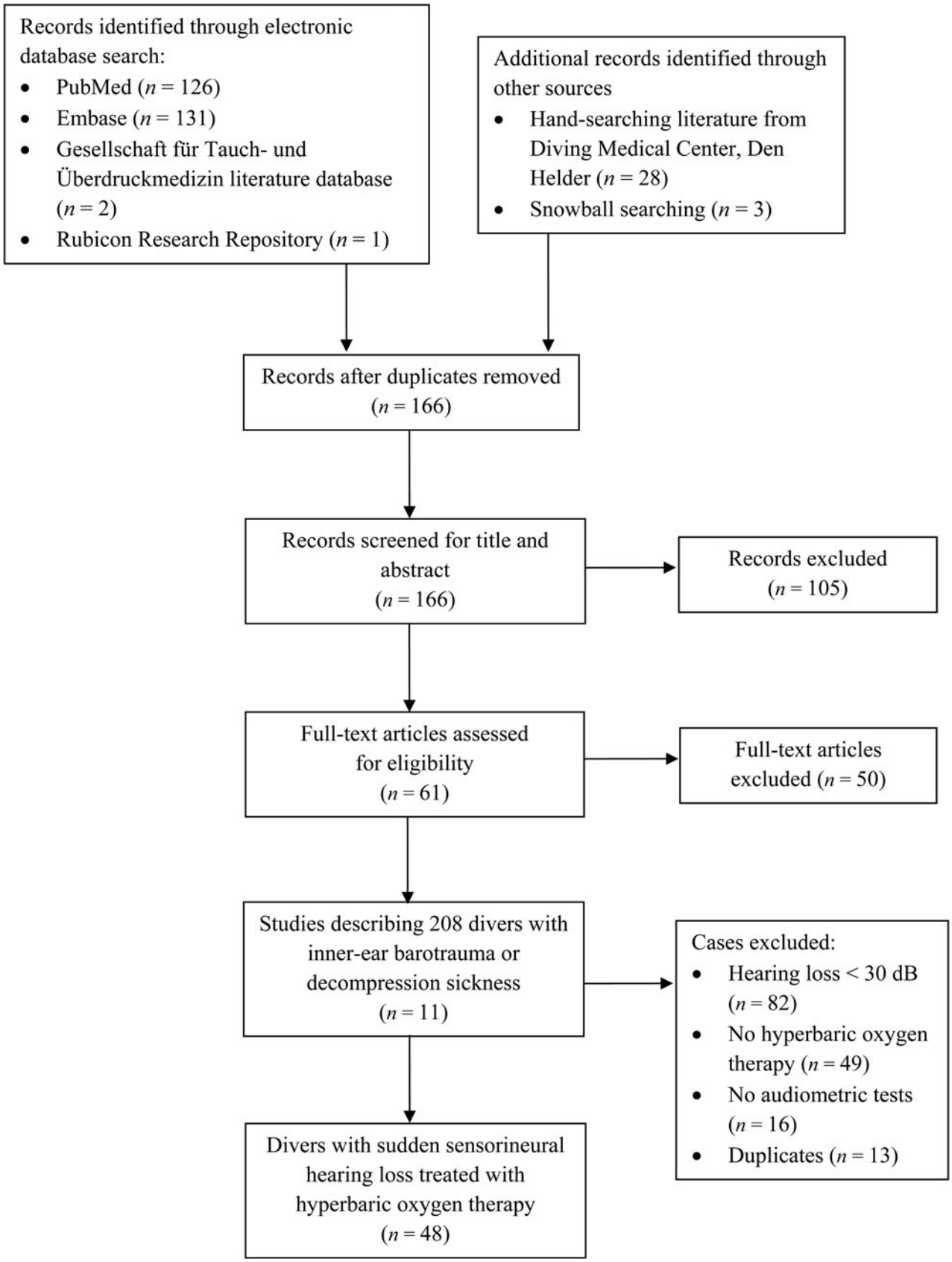



FIG. 1
Flow diagram showing the study selection process.

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the right ear. There was no tinnitus, dizziness or nausea. Computed tomography showed no middle- and inner-ear abnormalities, in particular, no air in the cochlea. Pure tone audiometry revealed right-sided hearing loss affecting the low frequencies (low Fletcher index = 68 dB, high Fletcher index = 53 dB) and 50 per cent speech discrimination at 80–100 dB. The patient was treated with 50 mg prednisone for 7 days and 10 daily hyperbaric oxygen therapy sessions (250 kPa × 75 minutes) on weekdays. Two days after the last hyperbaric oxygen session, pure tone audiometry showed persistent hearing loss in the low frequencies (low Fletcher index = 27 dB, high Fletcher index = 13 dB). Speech discrimination had improved to 100 per cent at 75 dB. Audiometric analysis one month later showed similar results.

*Case study 3*

A 29-year-old Navy diver woke up with right-sided hearing loss 2 days after a dive and developed tinnitus later that day. The diving profile was a maximum diving depth of 9 m and a diving time of 20 minutes; the dive finished with rapid ascent from 9 m. During the dive, no pain or middle-ear clearing difficulties were experienced. Pure tone audiometry showed right-sided hearing loss mainly affecting the low frequencies (low Fletcher index = 73 dB, high Fletcher index = 57 dB). Magnetic resonance imaging showed no abnormalities and serological tests were normal. The patient was treated with prednisone for 8 days on a tapering schedule (80, 80, 60, 60, 40, 40, 20 and 20 mg) and 10 daily hyperbaric oxygen therapy sessions on weekdays. After six hyperbaric oxygen therapy sessions, pure tone audiometry showed a marked improvement (maximum hearing loss at 4 kHz of 30 dB). Four days after the last hyperbaric oxygen therapy session, pure tone audiometry showed complete recovery of hearing. Audiometric analysis 9 months later showed similar results.

*Published case reports*

In addition to the 3 case reports described above, 48 case reports of divers with sudden SNHL and treated with hyperbaric oxygen therapy were retrieved from a literature search (Figure 1).[7,23,29–37]

All divers were male, with a mean age of 36 years. The median maximum diving depth was 35 m and the median diving time was 40 minutes. Most divers (65 per cent) used compressed air as the diving gas. The mean hearing loss was 58 dB, and 73 per cent of divers experienced vestibular symptoms that developed after a median of 15 minutes after diving. Divers were treated after a median time of 333 minutes with a median of 3 hyperbaric oxygen sessions. In 10 per cent of cases, divers were additionally treated with corticosteroids. Hearing improved in response to hyperbaric oxygen therapy in 80 per cent of cases: 39 per cent had some improvement and 41 per cent had a full recovery. In 20 per cent of cases, no hearing improvement was detected (Table I). There were no reports of hearing deterioration in response to hyperbaric oxygen therapy.

There were no statistical differences in vestibular symptoms, use of hyperbaric oxygen US Navy Treatment Table 6 or corticosteroid use between responders and non-responders to hyperbaric oxygen therapy. Further, there were no differences in maximum diving depth, time between dive and symptom onset, and time between symptom onset and start of hyperbaric oxygen therapy in divers who responded to hyperbaric oxygen therapy and those who did not. Responding divers had received more hyperbaric oxygen sessions than non-responding divers, although this difference was not statistically significant ($z$ score = −1.74; Table II).

## Discussion

An analysis of 51 divers with sudden SNHL showed that hyperbaric oxygen therapy resulted in at least some reversal of hearing loss in 80 per cent of cases. The therapeutic effect of hyperbaric oxygen therapy appeared to be greater for divers who received more therapy sessions. The clinical relevance of hyperbaric oxygen therapy, however, is difficult to assess

TABLE I
BASELINE CHARACTERISTICS OF DIVERS WITH SUDDEN SNHL TREATED WITH HBOT*

| Characteristic | Pts (*n*) | Value† |
|---|---|---|
| Age (years) | 28 | 36 (10) |
| Maximum dive depth (m) | 47 | 35 (26–72) |
| Diving time (min) | 35 | 40 (30–48) |
| Hearing loss (dB) | 29 | 58 (16) |
| Time between dive and symptom onset (min) | 48 | 15 (0–30) |
| Time between symptom onset and HBOT (min) | 49 | 333 (170–1440) |
| Number of HBOT sessions | 46 | 3 (1–7) |
| Follow up (months) | 49 | 0.25 (0–3) |
| Male | 40 | 100 |
| Diving gas | | |
| – Compressed air | 46 | 65 |
| – Surface-supplied air | 46 | 7 |
| – Helium–oxygen | 46 | 26 |
| – Trimix | 46 | 2 |
| Vestibular symptoms | 51 | 73 |
| HBOT with USN6 or RN62 | 45 | 40 |
| Additional corticosteroid treatment | 51 | 10 |
| Result | | |
| – No effect | 51 | 20 |
| – Improvement | 51 | 39 |
| – Full recovery | 51 | 41 |
| Diagnosis | | |
| – IEDS | 51 | 94 |
| – IEBT | 51 | 6 |

*$N$ = 51. †Non-parametric continuous data are reported as medians (Q1–Q3); parametric continuous data are reported as means (SD); non-continuous data are presented as percentages. SNHL = sensorineural hearing loss; HBOT = hyperbaric oxygen therapy; Pts = patients; Q1 = first quartile; Q3 = third quartile; SD = standard deviation; min = minutes; trimix = oxygen, nitrogen, helium; USN6 = United States Navy Treatment Table 6; RN62 = Royal Navy Table 62; IEDS = inner-ear decompression sickness; IEBT = inner-ear barotrauma

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TABLE II
STATISTICAL ANALYSIS OF DIVERS WITH SUDDEN SNHL TREATED WITH HBOT

| Characteristic | Responders* ($n = 41$) | Non-responders† ($n = 10$) | Statistic |
|---|---|---|---|
| Vestibular symptoms | | | $p = 0.432$ |
| – Yes | 31 | 6 | |
| – No | 10 | 4 | |
| HBOT type | | | $p = 1.00$ |
| – USN6 or RN62 | 14 | 4 | |
| – Other | 22 | 5 | |
| Additional corticosteroid treatment | | | $p = 0.569$ |
| – Yes | 5 | 0 | |
| – No | 36 | 10 | |
| Maximum diving depth (m) | 32 (27–64) | 44 (20–91) | $z = -0.085$ |
| Time between dive and symptom onset (min) | 15 (3–30) | 20 (0–45) | $z = -0.669$ |
| Time between symptom onset and HBOT (min) | 338 (128–1440) | 325 (233–2430) | $z = -0.651$ |
| Number of HBOT sessions | 4 (1–7) | 1 (1–3) | $z = -1.74$ |

Non-parametric continuous data are reported as medians (Q1–Q3), parametric continuous data are reported as means (standard deviation), non-continuous data are reported as percentages. *Divers whose hearing improved or recovered completely in response to HBOT. †Divers whose hearing did not improve in response to HBOT. SNHL = sensorineural hearing loss; HBOT = hyperbaric oxygen therapy; USN6 = US Navy Treatment Table 6; RN62 = Royal Navy Table 62; min = minutes; Q1 = first quartile; Q3 = third quartile

because spontaneous improvement in sudden SNHL of up to 65 percent has been reported in the general population.[1,38]

*Published case series*

Smerz studied hearing loss in 10 divers who presented with isolated inner-ear decompression sickness and were treated with hyperbaric oxygen therapy.[37] The hearing of all divers showed a clinical improvement: half made a full recovery and half retained some hearing deficit after the last treatment session. Shupak *et al.* studied inner-ear decompression sickness in 11 recreational divers treated with hyperbaric oxygen therapy, of whom 8 experienced hearing loss: 3 of these (38 per cent) made a full recovery and 5 (62 per cent) suffered residual hearing loss.[35] Nachum *et al.* reported inner-ear decompression sickness with cochlear involvement in 21 sport compressed air divers treated with hyperbaric oxygen therapy: 6 (29 per cent) made a full recovery, 8 (38 per cent) had improved audiological test findings and 7 (33 per cent) had no hearing improvement after therapy.[32] Farmer *et al*. reported the cases of 11 divers suffering from inner-ear decompression sickness with hearing loss, who were treated with hyperbaric oxygen therapy.[31] Eight divers (73 per cent) made a good recovery and three (27 per cent) experienced no hearing improvement. Klingman *et al.* reported hearing loss in 10 divers with inner-ear decompression sickness that was treated with hyperbaric oxygen therapy and corticosteroids.[7,23,33] Five divers (50 per cent) made a full recovery and five (50 per cent) had residual hearing loss after treatment. One diver with inner-ear barotrauma and hearing loss also underwent hyperbaric oxygen therapy: this patient experienced a remarkable hearing improvement from 80 dB to 15 dB after treatment.

Studies into the effectiveness of hyperbaric oxygen therapy in non-divers with sudden SNHL have reported mixed results. In 2012, the value of hyperbaric oxygen therapy for idiopathic sudden SNHL and tinnitus in non-divers was assessed in a Cochrane Review.[39] A pooled analysis revealed that hyperbaric oxygen therapy significantly increased the proportion of patients gaining a 25 per cent hearing improvement ($p = 0.02$). Five patients had to be treated to obtain one good outcome. Bennett *et al.* concluded that although hyperbaric oxygen therapy had a beneficial effect, it was difficult to assess its clinical relevance because of the 'modest number of patients, methodological shortcomings and poor reporting'. In addition, Aslan *et al.* reported significant hearing improvement in 25 non-divers with idiopathic sudden SNHL treated with hyperbaric oxygen therapy (in addition to conventional therapy) compared with a control group receiving conventional therapy only.[28] In two separate studies, Çekin *et al.* and Satar *et al.* compared hyperbaric oxygen therapy with conventional therapy, but reported no significant difference in the beneficial effects of both therapies.[40,41] In a retrospective analysis, Kestler *et al.* investigated the effect of hyperbaric oxygen therapy in 49 sudden SNHL patients and found it to be comparable to spontaneous recovery rates.[42] They concluded that hyperbaric oxygen therapy had no additional value as a primary treatment option for sudden SNHL. Comparing these results to our own data suggests that hyperbaric oxygen therapy may be more effective in divers than in the general population. This difference might be caused by the different pathophysiological mechanisms for sudden SNHL in divers (inner-ear barotrauma and inner-ear decompression sickness) and the general population (viral, vascular and autoimmune causes).

US Navy Treatment Table 6 is the most frequently used hyperbaric oxygen treatment table.[11,22,24,29,32,34–36] The present study showed a similar level of usage of US Navy Treatment Table 6 between responders and non-responders (Table II), suggesting that this

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treatment table is not superior to others. Several other studies also reported no difference in therapeutic outcome between different treatment tables.[22,37]

There are no published recommendations on the optimal number of hyperbaric oxygen treatments for sudden SNHL in divers. The Undersea and Hyperbaric Medical Society recommends 10–20 hyperbaric oxygen treatments for sudden SNHL in non-divers.[5,43] The present study found that responding divers received more hyperbaric oxygen treatment sessions than non-responding divers (four versus one, $z$ score = −1.74). Although the difference was not statistically significant, it suggests that a higher number of hyperbaric oxygen treatments is associated with a better treatment outcome. This has also been suggested by previous studies reporting a beneficial effect of hyperbaric oxygen therapy after 10–20 sessions.[5,28,40,44] It is therefore possible that the non-responding divers from our analysis could have benefited from more hyperbaric oxygen therapy sessions.

### *Strengths and limitations*

The present analysis of 51 divers with sudden SNHL and treated with hyperbaric oxygen therapy is the largest of its kind. Unfortunately, the analysis was hindered by several different kinds of bias. First of all, publication bias might have a major effect on the results. Reports of divers with a good response to hyperbaric oxygen therapy are more likely to be published than studies in which no positive effect of hyperbaric oxygen therapy was found. As a result, the beneficial effect of hyperbaric oxygen therapy might be overestimated in the present analysis.

Another limiting factor is that the cases included in this analysis were not extracted from clinical trials and patients consequently had different diagnostic tests, additional treatments and lengths of follow up. The most important difference was the variation in audiological testing.[7,23,29–37] Some divers were not subjected to pure tone audiometry before the start of hyperbaric oxygen therapy. Instead, audiological evaluation took place either between therapy sessions or after the last treatment. This might have led to underestimation of the beneficial effect of hyperbaric oxygen therapy as the effect of the first session(s) was excluded from the analysis.

Another factor that may have led to underestimation of the therapeutic effect of hyperbaric oxygen is the inclusion of some cases with a long treatment delay. Limited research suggests that the best therapeutic effect is achieved with a shorter treatment delay.[22,23,31,32,35] The present analysis included two cases with a considerable delay between symptom onset and the start of hyperbaric oxygen therapy (Table III): these divers commenced treatment after 5 and 14 days, respectively, after symptom onset and experienced no hearing improvement. The therapeutic effect of hyperbaric oxygen is likely to be greatest in the first hours or days after symptom onset. The inner ear is a delicate structure, and diving-related damage to the cochlea can progress to permanent damage within a short period.[45] Consequently, therapy should be initiated as soon as possible.[22,23,31,32,35] These conclusions are based on clinical experience, pathophysiology and published reports. However, they are not supported by the statistical analysis in this report since there was no significant difference in the length of time between symptom start and hyperbaric oxygen therapy between responders and non-responders ($z$ score = −0.651). Excluding the two cases with long treatment delays from the analysis had no effect ($z$ score = −0.539). However, this may be the result of the small study populations included in the present analysis.

The median follow up of cases included in the present study was only 0.25 months (Table I), which made it impossible to draw conclusions on the long-term effects of hyperbaric oxygen therapy. The absence of long-term follow up for divers with sudden SNHL has been noted in previous studies.[23,35] However, this is unlikely to represent a weakness of the present study because most of the therapeutic effects of hyperbaric oxygen are expected to take place directly after the initial damage. If no hearing improvement is found shortly after therapy, then spontaneous recovery is not expected to occur later. The three divers treated in our hyperbaric oxygen therapy facility showed no change in hearing loss at 1, 9 and 11 months, respectively, following hyperbaric oxygen therapy (Table III). Furthermore, deterioration is seldom seen in the late recovery phase.

### *Safety*

Hyperbaric oxygen therapy appears to be a safe therapy since no side effects or adverse events were published in the case reports. Only one adverse event occurred during treatment in our own hyperbaric oxygen therapy facility: a diver experienced nausea during one therapy session, which resolved spontaneously during the session. Furthermore, none of the divers included in this analysis experienced hearing deterioration during hyperbaric oxygen therapy.

Three divers with hearing loss due to inner-ear barotrauma were included in the analysis. These cases were of special interest because some experts believe that hyperbaric oxygen therapy can increase cochlea damage in patients with inner-ear barotrauma.[31] The hyperbaric conditions that patients experience during hyperbaric oxygen therapy may simulate the conditions that initially caused the inner-ear barotrauma. However, the present results do not support this theory since no adverse events or deterioration of hearing loss were reported for the divers with inner-ear barotrauma, although the small sample size ($n = 3$) means that this finding should be interpreted with caution. Future research is necessary to confirm these results.

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TABLE III
CHARACTERISTICS OF DIVERS WITH SUDDEN SNHL TREATED WITH HBOT

| Ref | Diver no | Age (y) | Diving depth (m) | Diving time (min) | Diving gas* | HL (dB)† | Vestibular symptoms | Time until symptoms (min) | Time until HBOT (min) | Type of HBOT‡ | No of HBOT sessions | Result** | CS | FU (mo) | Diagnosis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 1 | 25 | 46 | – | 1 | 43§ | Yes | 0 | 2880 | 0 | 1 | 1 | No | 3 | IEBT |
| 30 | 2 | – | – | – | – | – | Yes | – | – | 1 | 1 | 0 | No | 0 | IEBT |
| 31 | 3 | 36 | 137 | – | 2 | 67§ | No | 0 | 300 | 1 | 1 | 0 | No | 0 | IEDS |
| | 4 | – | 137 | – | 2 | – | No | 206 | 66 | 1 | 1 | 0 | No | 0 | IEDS |
| | 5 | – | 107 | – | 2 | – | No | 0 | 17 | 1 | 1 | 2 | No | 0 | IEDS |
| | 6 | – | 107 | – | 2 | – | No | 0 | 21 | 1 | 1 | 2 | No | 0 | IEDS |
| | 7 | – | 76 | – | 2 | – | No | 0 | 350 | 1 | 1 | 0 | No | 0 | IEDS |
| | 8 | – | 107 | – | 2 | – | Yes | 0 | 5 | 1 | 1 | 2 | No | 0 | IEDS |
| | 9 | – | 49 | – | 2 | – | Yes | 25 | 19 | 1 | 1 | 2 | No | 0 | IEDS |
| | 10 | – | 107 | – | 2 | – | Yes | 0 | 17 | 1 | 1 | 2 | No | 0 | IEDS |
| | 11 | – | 198 | – | 2 | 45§ | Yes | 0 | 10 | 1 | 1 | 2 | No | 0 | IEDS |
| | 12 | – | 198 | – | 2 | 45§ | Yes | 0 | 10 | 1 | 1 | 2 | No | 0 | IEDS |
| | 13 | – | 198 | – | 2 | 45§ | Yes | 0 | 10 | 1 | 1 | 2 | No | 0 | IEDS |
| 32 | 14 | 45 | 50 | 180 | 0 | 80 | Yes | 5 | 540 | 0 | 9 | 1 | No | 0 | IEDS |
| | 15 | 22 | 25 | 40 | 0 | – | Yes | 60 | 60 | 0 | 1 | 2 | No | 8 | IEDS |
| | 16 | 35 | 20 | 40 | 0 | – | Yes | 45 | 840 | 1 | 7 | 0 | No | 0.25 | IEDS |
| | 17 | 32 | 15 | 50 | 0 | 80 | Yes | 20 | 315 | 0 | 3 | 2 | No | 0.25 | IEDS |
| | 18 | 42 | 30 | 30 | 0 | 45 | Yes | 10 | 240 | 0 | 2 | 2 | No | 119 | IEDS |
| | 19 | 24 | 30 | 35 | 0 | 80 | No | 120 | 4320 | – | 3 | 1 | No | 42 | IEDS |
| | 20 | 29 | 122 | 22 | 0 | 60 | Yes | 0 | 270 | 1 | 7 | 1 | No | 1 | IEDS |
| | 21 | 28 | 50 | 30 | 0 | 70 | No | 0 | 20160 | – | 1 | 0 | No | 29 | IEDS |
| | 22 | 28 | 30 | 42 | 0 | 68 | Yes | 20 | 315 | 0 | 7 | 1 | No | 20 | IEDS |
| | 23 | 30 | 29 | 42 | 0 | 63 | Yes | 15 | 195 | 0 | 5 | 1 | No | 2 | IEDS |
| | 24 | 57 | 20 | 60 | 0 | 40 | Yes | 30 | 240 | 0 | 7 | 1 | No | 23 | IEDS |
| | 25 | 37 | 30 | 30 | 0 | 35 | Yes | 40 | 360 | 0 | 2 | 2 | No | 2.5 | IEDS |
| | 26 | 36 | 38 | 45 | 0 | 65 | Yes | 20 | 240 | 0 | 5 | 0 | No | 0.25 | IEDS |
| | 27 | 35 | 20 | 60 | 0 | 65 | Yes | 45 | 210 | 0 | 2 | 0 | No | 0.5 | IEDS |
| | 28 | 69 | 68 | 29 | 0 | 70 | No | 5 | 1500 | 0 | 8 | 1 | No | 0.5 | IEDS |
| | 29 | 41 | 22 | 40 | 0 | 85 | No | 300 | 2880 | 0 | 3 | 1 | No | 1 | IEDS |
| | 30 | 24 | 30 | 30 | 0 | 45 | Yes | 5 | 2040 | 0 | 4 | 2 | No | 0.25 | IEDS |
| 33 | 31 | – | 32 | 35 | – | 30 | No | – | 1260 | – | – | 2 | No | 4 | IEDS |
| 34 | 32 | 47 | 50 | 67 | 0 | 50 | Yes | 10 | 510 | 0 | 6 | 1 | Yes | 1 | IEDS |
| 35 | 33 | 41 | 32 | – | – | – | Yes | 30 | 774 | 0 | – | 0 | No | 58 | IEDS |
| 36 | 34 | 44 | 17 | 15 | 1 | 50 | Yes | 20 | 7200 | 0 | 3 | 0 | No | 3 | IEDS |
| | 35 | 38 | 35 | 45 | 1 | – | Yes | 15 | – | 0 | 4 | 1 | No | 0.13 | IEDS |
| 23 | 36 | 40# | – | – | – | 80 | No | – | 1440 | – | – | 1 | Yes | 5 | IEBT |
| 37 | 37 | 46# | 38 | 40 | 0 | ≥ 20 | Yes | 30 | 360 | 1 | 6 | 2 | No | 0 | IEDS |
| | 38 | 46# | 27 | 30 | 0 | ≥ 20 | Yes | 30 | 240 | 1 | 6 | 2 | No | 0 | IEDS |
| | 39 | 46# | 27 | 25 | 0 | ≥ 20 | Yes | 20 | 360 | 1 | 7 | 1 | No | 0 | IEDS |
| | 40 | 46# | 60 | 30 | 0 | ≥ 20 | Yes | 10 | 360 | 1 | 6 | 1 | No | 0 | IEDS |
| | 41 | 46# | 27 | 40 | 0 | ≥ 20 | Yes | 30 | 140 | 1 | 26 | 1 | No | 0 | IEDS |
| | 42 | 46# | 21 | 30 | 0 | ≥ 20 | Yes | 60 | 720 | 1 | 5 | 1 | No | 0 | IEDS |
| | 43 | 46# | 23 | 35 | 0 | ≥ 20 | Yes | 20 | 2110 | 1 | 4 | 1 | No | 0 | IEDS |
| | 44 | 46# | 24 | 40 | 0 | – | Yes | 15 | 180 | 1 | 2 | 2 | No | 0 | IEDS |
| | 45 | 46# | 27 | 30 | 0 | – | Yes | 10 | 1440 | 1 | 1 | 2 | No | 0 | IEDS |

*Continued*

Table III *Continued*

| Ref | Diver no | Age (y) | Diving depth (m) | Diving time (min) | Diving gas* | HL (dB)† | Vestibular symptoms | Time until symptoms (min) | Time until HBOT (min) | Type of HBOT‡ | No of HBOT sessions | Result** | CS | FU (mo) | Diagnosis |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 46 | 46# | 12 | 52 | 0 | ≥ 20 | Yes | 10 | 1440 | 1 | 7 | 2 | No | 0 | IEDS |
| 7 | 47 | 30 | 50 | 65 | 0 | 35 | Yes | 15 | 90 | – | – | 1 | No | – | IEDS |
| | 48 | 35 | 55 | 60 | 3 | 50 | Yes | 30 | 180 | – | – | 1 | No | – | IEDS |
| DMS | 49 | 43 | – | – | – | 72§ | No | 0 | 4320 | 1 | 10 | 2 | Yes | 11 | IEDS |
| | 50 | 29 | 81 | 125 | 2 | 53§ | No | 15 | 1440 | 1 | 10 | 1 | Yes | 1 | IEDS |
| | 51 | 29 | 9 | 20 | 0 | 57§ | No | 2580 | 4320 | 1 | 10 | 2 | Yes | 9 | IEDS |

*0 = compressed air; 1 = surface-supplied air; 2 = trimix (oxygen, nitrogen, helium); 3 = helium–oxygen. †Reported as hearing loss defined by article describing the case. ‡HBO treatment table: 0 = US Navy Treatment Table 6 or Royal Navy Table 62, 1 = other. **0 = no effect; 1 = improvement in pure tone audiometry and/or speech discrimination test; 2 = full recovery of hearing. §Reported as high Fletcher index. #Mean values reported in article describing the case; these values were not used in the statistical analysis. SNHL = sensorineural hearing loss; HBOT = hyperbaric oxygen therapy; Ref = reference; – = unknown or not reported; No = number; y = years; min = minutes; CS = corticosteroids; FU = follow up; HL = hearing loss; mo = months; IEBT = inner-ear barotrauma; IEDS = inner-ear decompression sickness; DMS = Dive Medical Center, Royal Netherlands Navy, Den Helder

- **Sudden sensorineural hearing loss in divers is caused by inner-ear barotrauma or inner-ear decompression sickness**
- **There is no consensus on the best treatment options for sudden sensorineural hearing loss in divers and general population**
- **This study evaluated the therapeutic effect of hyperbaric oxygen therapy in 51 divers with sudden sensorineural hearing loss**
- **Hyperbaric oxygen therapy resulted in hearing improvement in 80 per cent of divers**
- **Responding divers had received more hyperbaric oxygen therapy sessions**

*Clinical implications*

This analysis confirmed that hyperbaric oxygen therapy can improve hearing when applied as a primary treatment for sudden SNHL in divers. Since diving is increasing in popularity, more cases of sudden SNHL in divers are likely to be encountered in the future. In addition, the number of hyperbaric oxygen therapy facilities is increasing and more divers receive this therapy for diving-related injuries. The proportion of divers undergoing hyperbaric oxygen therapy for inner-ear decompression sickness rose from 45 per cent in 2003 to 89 per cent in 2005.[23] All of these developments can drive research efforts. Future clinical trials into the therapeutic effects of hyperbaric oxygen therapy for sudden SNHL in divers are anticipated to support the present findings.

## Conclusion

Hyperbaric oxygen therapy resulted in hearing improvement in 80 per cent of divers with sudden SNHL. This type of therapy is more effective if more therapy sessions are received.

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