Original articles

Decompression illness in Finnish technical divers: a follow-up study on incidence and self-treatment

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Abstract
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Introduction: Technical diving is increasing in popularity in Finland, and therefore the number of decompression illness (DCI) cases is also increasing among technical divers. Although hyperbaric oxygen treatment (HBOT) remains the standard of care, there are anecdotal reports of technical divers treating mild DCI symptoms themselves and not seeking a medical evaluation and possible recompression therapy. This study aimed to make an epidemiologic inventory of technical diving-related DCI symptoms, to establish the incidence of self-treatment and to determine the apparent effectiveness of different treatment methods.
Methods: A one-year prospective survey with online questionnaires was conducted. Fifty-five experienced and highly trained Finnish technical divers answered the survey and reported their diving activity, DCI symptoms, symptom treatment, and treatment outcome.
Results: Of the reported 2,983 dives, 27 resulted in symptoms of DCI, which yielded an incidence of 91 per 10,000 dives in this study. All of the reported DCI symptoms were mild, and only one diver received HBOT. The most common self-treatments were oral hydration and rest. First aid oxygen (FAO_2) was used in 21% of cases. Eventually, none of the divers had residual symptoms.
Conclusions: The incidence of self-treated DCI cases was 27 times higher than that of HBO-treated DCI cases. There is a need to improve divers' awareness of the importance of FAO_2 and other recommended first aid procedures and to encourage divers to seek medical attention in case of suspected DCI.

Introduction

Scuba diving in Finland can be challenging due to poor visibility and chilling water temperatures. Year round, the temperature is 4°C at depths below 30 metres. Furthermore, during the winter months, the surface water temperature is nearly freezing and varies from -1 to 2°C. Abandoned mines with crystal clear water and deep passages have become very popular dive sites instead of murky lakes. However, deep passages mean deep diving, which in turn requires demanding technical training. Technical divers use advanced equipment and mixed breathing gases, such as nitrox or trimix, in order to do dives that are deeper and/or longer than recreational dives. Furthermore, deep dives lead to long exposures in cold water. Despite these challenging conditions, Finnish divers commonly perform decompression dives. Figure 1 shows the crystal clear, but cold 4°C water found in Finnish mines.

It is known that deep trimix dives and cold are important risk factors for decompression illness (DCI).[1,2] The average number of recompressed DCI patients in Finland is 29 per year (range 16–38).[3] An increasing number of cases with technical divers has been described over the years, reflecting the increasing popularity of technical diving in the Finnish diving community.[3] Anecdotal reports of technical divers treating mild DCI symptoms themselves, or even denying the symptoms and not seeking a recompression facility, are not unusual. However, there are no data describing how often this occurs, how severe the cases are, and how cases are self-treated or managed.

Figure 1
Finnish technical divers at a crushing station at 138 metres of fresh water in the Montola mine, Finland; photo by Patrik Grönqvist

Recompression in a chamber to facilitate hyperbaric oxygen treatment (HBOT) is the standard care for DCI. Nonetheless, given the favourable natural history of 'mild' DCI[4] it has been suggested that some mild DCI cases might be managed without recompression, especially if it is difficult or dangerous to access as is often the case in remote locations. The consensus guideline for pre-hospital management of DCI from 2018 defines mild symptoms as musculoskeletal pain, rash, constitutional symptoms, subcutaneous swelling, and some cutaneous sensory changes.[4] Even in apparently mild cases, significant neurological dysfunction should be excluded by a competent examiner, and designation of a case as mild (and not in need of recompression) should always involve a diving medicine physician.[4,5]

The common practice for early management of DCI is to breathe normobaric first aid oxygen (FAO_2), hydrate orally, lie down in a horizontal position, and keep warm but not hyperthermic. Treatment with a non-steroidal anti-inflammatory drug is also appropriate if there are no contra-indications.[4–6] Furthermore, the use of normobaric FAO_2 increases recompression efficacy and decreases the number of recompression treatments required if given within four hours after surfacing.[7] There is also evidence that diving causes dehydration, which would at least in theory support the role of post-dive hydration.[8]

Another option for early management of DCI is to perform in-water recompression (IWR). One significant advantage of IWR is the ability to treat the diver within a short time frame from symptom onset. However, this method is controversial due to the potential risks and the difficulty in selecting the divers whose condition justifies the risks of IWR.[9] The greatest concern is for central nervous system (CNS) oxygen toxicity and the risk of drowning in case of a seizure. Thus, IWR should only be performed in cases when the patient's safety can be ensured and with appropriate training, equipment, and a full understanding of the necessary procedures.[5,6,9] Technical divers are in a unique position to potentially perform IWR due to their high level training, advanced equipment, good supporting divers and easy access to 100% oxygen. Technical diving is more often done in remote locations and conditions in caves and mines are usually predictable. On the other hand, there is indefinite evidence that a delay in recompression would have a negative effect on the treatment outcome, except in the severe cases.[9,10] Therefore, further studies are needed to address this issue.

The aim of this research was to determine the incidence of technical diving-related DCI symptoms in Finnish divers, to find out if self-treatment occurs, and to determine the effectiveness of different treatment methods. Most of what is known about the incidence of DCI is based on data related to cases requiring hyperbaric treatment.[11–13] In addition, there are only a few prospective and retrospective studies with data on DCI symptoms and treatment outcomes gathered with questionnaires from recreational divers.[14–18]

Methods

Ethical approval was granted by the Ethical Committee of Helsinki University Hospital (HUS/976/2019). The study adhered to the Declaration of Helsinki.

STUDY DESIGN

The study was designed as a prospective longitudinal cohort study. The target group consisted of experienced technical divers who planned to take part in a one-year follow-up carried out with online questionnaires. Participants were recruited from the Finnish recreational technical diving community. Researchers contacted known technical divers at Finnish dive sites and via email. Trained technical divers who perform decompression dives with mixed breathing gases in caves, mines, or wrecks were included in this study. All subjects participated voluntarily and gave their informed consent for the study. The researchers did not examine any of the subjects, and the divers were free to dive according to their usual diving practice.

DATA GATHERING

Three online questionnaires were created on Microsoft Office 365 Forms (Microsoft Corp., Redmond, Washington, USA) under license from Helsinki University Hospital. In order to answer the questionnaires anonymously, the participants were given a research identity code that was used to combine information from different questionnaires. Only the researcher responsible for recruitment (LT) was aware of the identities in order to keep track of the answers given.

Information containing sex, age, and anthropometric data (height, weight) were requested in the first questionnaire (Questionnaire for Demographic Data) (*Appendix 1). Body mass index (BMI) was calculated based on the reported data. Additional information on previous HBOT-treated DCI, the use of nicotine-containing products, and diving history were also requested in this questionnaire.

The second questionnaire (Questionnaire for Diving Activity) (*Appendix 2) collected data on the number of dives, the depth range, and the maximum depth during the one-year follow-up period from 01 July 2020 to 30 June 2021. The divers completed this questionnaire every two months, thus six times during the follow-up period.

The third questionnaire (Questionnaire for DCI Symptoms) (*Appendix 3) collected data about the dives that led to possible DCI-related symptoms, the diver's symptom profile, how these symptoms were treated, and treatment outcome. The divers were instructed to complete the third questionnaire each time symptoms occurred.

STATISTICS

Continuous variables are presented using medians and interquartile ranges (IQRs), while categorical variables are presented using counts and percentages. The divers were divided into two groups: the divers who experienced DCI symptoms ('DCI'); and the divers who did not experience any DCI symptoms ('no DCI') during the one-year follow-up period. The groups were compared using Mann-Whitney U tests for continuous variables and Fisher's exact tests for categorical variables. P-values < 0.05 were considered significant. All analyses were done using IBM SPSS Statistics version 27 (IBM Corp, Armonk, NY, USA).

Results

SUBJECTS

Fifty-five volunteers (nine women, 46 men) met the criteria and were included in the study. Three divers declined to participate in this research. All study participants responded to every questionnaire. The average diving experience was 16 years (range 5–51 years). The divers were highly trained: 84% had their highest certification as full cave or equivalent and 75% had full trimix or equivalent; 25% of divers had normoxic trimix or equivalent. Fifty divers (91%) used a closed-circuit rebreather (CCR), and five divers (9%) utilised open-circuit (OC) scuba. Fifteen divers were active instructors who taught technical diving mostly in Finland during this period. There was no statistically significant difference in demographic data between the divers who experienced DCI symptoms (n = 17) and the divers who did not have any symptoms (n = 38). The demographics are shown in Table 1.

Table 1

Description of 55 participants; divers in the DCI group reported at least one dive leading to DCI symptoms. Data are simple numbers or median (IQR). There was no statistical difference between the groups in any parameter. HBO – hyperbaric oxygen

Parameter	DCI n = 17	No DCI n = 38
Male	13	33
Age, years	43 (40–50.5)	47 (40.8–50.3)
Body mass index, kg·m^{-2}	27.1 (24.5–28.7)	26.5 (24.5–28.1)
Smoking	2	4
Previous DCI treated with HBO	6	7
Diving years	18 (8–27)	13 (10–18)
Number of dives	1,000 (682–1,750)	800 (608–1,325)
Rebreather used	15	35
Full trimix or higher	13	27
Full cave or higher	14	32
Instructor	7	8

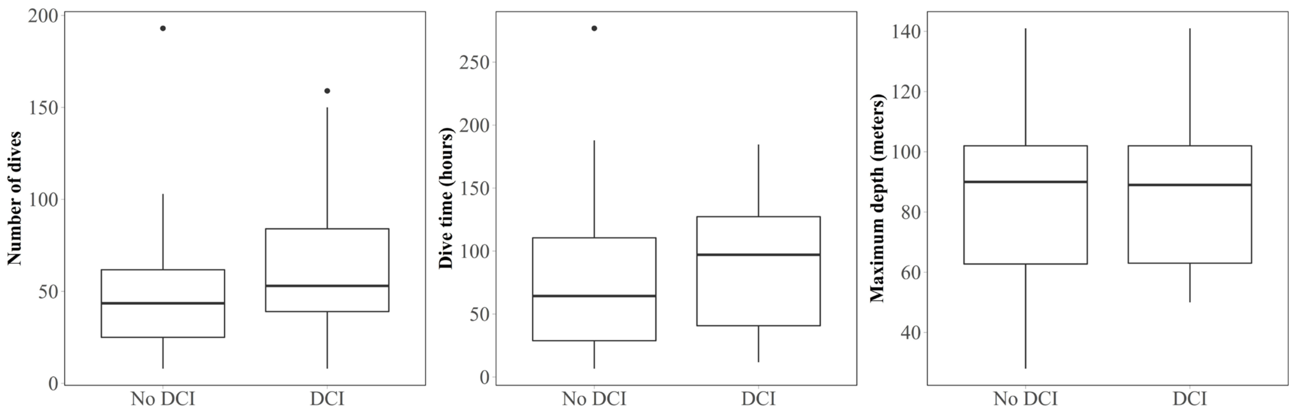
DIVING ACTIVITY

During the one-year follow-up period, the divers performed a total of 2,983 dives and 4,554 hours of dive time. Of these dives, 1,200 (40.2%) or 1,911 hours of dive time (42%), were done during the colder winter months (November to April). The maximum depth reached was 141 metres of fresh water (mfw) during the summer months and 137 mfw during the winter months. There was no significant difference in diving activity between the divers who experienced DCI symptoms and the divers who did not experience any DCI symptoms (P = 0.10). There was also no significant difference between these groups in respect of maximum depth (P = 0.91) or dive time (P = 0.24). Diving activity for the follow-up period is presented in Figure 2.

Footnote: * Appendices 1–3 are available on DHM Journal's website: https://www.dhmjournal.com/index.php/journals?id=294

Figure 2

The number of dives, dive time, and maximum depth stratified into groups reporting and not reporting DCI symptoms over the one-year study period. The boxes show median and first and third quartiles. The whiskers extend up to 1.5 times the IQR and observation outside that range are shown as dots. There was no statistical difference between groups on any of the three measures, *P*-values being 0.10, 0.24 and 0.91 respectively



SYMPTOMS

DCI-related symptoms occurred in 17 divers after 27 dives; thus, the apparent incidence of DCI was 91 per 10,000 dives in this study. The divers reported 33 dives followed by symptoms but after a review by three physicians in the research team, six cases were determined as not being caused by DCI: two divers had symptoms caused by hypercapnia, one suffered from dehydration due to diarrhoea with no DCI symptoms, one was diagnosed with immersion pulmonary oedema (IPO), one was suspected to have pulmonary oxygen toxicity, and one had a frostbite-type of sensation in his feet caused by a leaking dry suit.

Most of the reported symptoms were mild, only one diver reported severe symptoms (pulmonary symptoms, vertigo). The most common symptoms were joint pain (n = 12), muscle pain (n = 10), tingling/itching (n = 6), and skin rash, swelling, and warmth (n = 6). The majority of divers had two or three different symptoms at the same time, e.g., tingling/itching + joint pain + numbness or skin rash + fatigue. The symptoms are shown in Figure 3. In the majority of cases the symptoms appeared within two hours of surfacing (12/27, 44.4%) or within 24 hours (8/27, 29.6%). Some divers experienced symptoms directly after surfacing (3/27, 11.1%) or even underwater (4/27, 14.8%). Divers who experienced symptoms underwater became asymptomatic during decompression stops, but the symptoms reappeared at the surface. Nineteen (70%) of the incident dives took place during the summer months and eight dives (30%) during the winter months.

TREATMENT AND OUTCOMES

After experiencing mild DCI symptoms, the divers tended to self-treat. In 20 events (74%) the divers hydrated orally (more than they normally would after a dive) and in 19 events (70%) the divers rested. In only six events (21%) the divers used FAO_2 and in one event the diver reported not to have treated their symptoms at all. One diver performed an IWR after experiencing mild fatigue and skin rash, swelling, pain and warmth in the upper limb after a dive to 76 mfw with a total dive time of 179 minutes. The delay to perform the IWR was three days. IWR was performed with two safety divers and the diver was utilising a CCR with a maximum inspired PO_2 of 1.7 atmospheres (172.2 kPa). The IWR profile consisted of descent to 35 mfw for two minutes and then a very slow ascent (over 55 minutes) to a 6 mfw habitat. The total duration of the IWR was 120 minutes. The IWR was considered successful as the diver eventually made a complete recovery. The pain, warmth and skin rash had vanished during IWR, and the swelling resolved within a week. Only two symptomatic divers contacted a recompression facility. One had such mild symptoms that the hyperbaric physician decided not to treat the diver with hyperbaric oxygen (HBO) and the symptoms resolved after rest and FAO_2. The other diver (referred to above as having severe symptoms) was recompressed twice in a chamber and recovered completely. In twenty-five events the divers reported complete recovery with the treatment without contacting any medical personnel. In three of these cases the divers reported that their symptoms diminished after self-treatment, but they also commented that the symptoms gradually diminished and all symptoms were gone within several days taking them longer to recover fully. The treatment reported by divers is shown in Figure 4.

PROPOSED CONTRIBUTING FACTORS

The divers suggested possible contributing factors leading to their DCI symptoms on the questionnaire. The most common suggested factor was dehydration, n = 12 (43%), even though the divers underlined in their questionnaire answers that they drank a lot before dives. Another commonly suggested contributing factor was successive days of diving, n = 11 (39%). Finnish divers often spend a weekend at a diving

Figure 3
Reported DCI symptoms in 27 incident dives during a one-year follow-up period

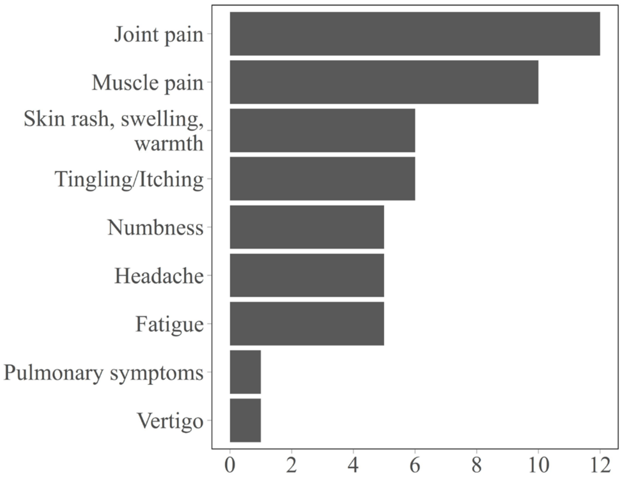
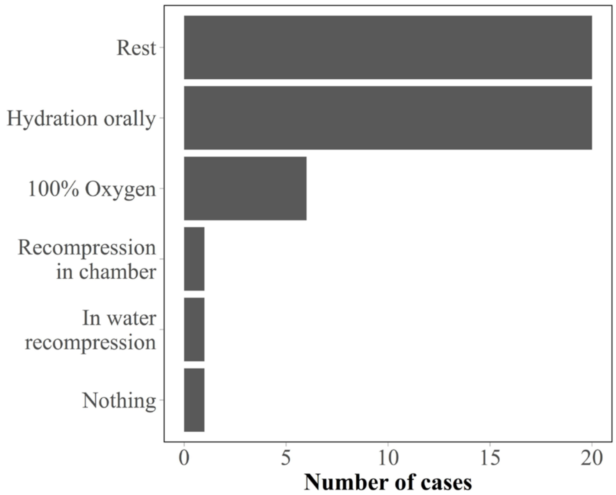


Figure 4
Initial treatment carried out by the divers after experiencing DCI symptoms; the diver might have used more than one initial treatment



site, as many of them are located far away from bigger cities. Therefore, it is common to dive two or three days consecutively. Surprisingly, only six divers (22%) described cold as a possible contributing factor despite extremely cold water temperatures.

Discussion

We hypothesised that demanding technical dives in an extremely cold environment involving many risk factors would be associated with a high incidence of DCI and that highly trained divers may practice self-treatment. In this study, the incidence of self-reported DCI symptoms was 91 per 10,000 dives, which is higher than in the previous questionnaire studies.[14–18] One study involved an analysis of the DAN Europe database including specific questionnaires for data collection, and reported the incidence of DCS at 81.8 per 10,000 dives, which is similar to our findings.[19] A literature review of questionnaire studies is summarised in Table 2.[14–19] In the present study, we recorded one case that received HBO for DCI symptoms among 2,983 dives (incidence of 3.3 per 10,000 dives). Although conditions were very cold and demanding this is consistent with a previous study done with technical divers in warm waters.[13] The majority of the injured divers in the present study treated themselves (n = 26, 96%) without receiving HBO. Most of the symptoms were so mild that the divers did not consider the need to contact a diving medicine physician.

In addition to the harsh diving environment, the high incidence might partly be explained by participation in a study with prospective data collection which may have encouraged divers to self-observe for symptoms more closely than usual. It has been suggested that an increase in annual diving is associated with fewer diving injuries.[17] This may explain why, despite the very cold conditions and demanding dives, we recorded mainly mild DCI symptoms although the incidence was high.

In our study, only six divers (21%) used FAO_2 after experiencing DCI symptoms, even though it is beneficial and recommended as soon as possible after the onset of symptoms.[5] This is an alarmingly low number, but it is consistent with earlier studies.[7,20] The assumption was that skilled and highly trained divers with easy access to oxygen would use FAO_2 more often. To determine why the great majority of these divers did not utilise FAO_2 after experiencing DCI symptoms, author LT interviewed some of the divers. The answers were "*symptoms were so mild or uncertain*", "*a little pain belongs to technical dives*", "*there are too many things to do after a dive, no time for oxygen*", "*some kind of shame in having symptoms*", "*do not know why I did not use it even though I teach other divers to use it*".

Despite the low number of divers using FAO_2 and only one diver receiving HBO, the outcomes were excellent. None of the divers had residual symptoms, and every diver eventually recovered. This is consistent with the present understanding that some mild DCI cases could be adequately managed without recompression with good outcome.[4,5]

Yet, along with rumors of technical divers treating mild DCI symptoms themselves, we have had anecdotal reports from diving physicians and divers themselves, of technical divers suffering recurrent mild DCI symptoms in the same part of the body and with the same symptoms very easily after their first incident. There is no scientific evidence supporting this, but it has raised concern that they might have some form of tissue damage predisposing divers to recurrent DCI or possibly long-term effects such as dysbaric osteonecrosis

Table 2
An overview of questionnaire-based studies on the incidence of DCI conducted on recreational divers

Location and citation	DCI cases	Dives	DCI cases per 10^4 dives	Years	Type of study
Sweden[14]	190	127,256	14.9	1999	Retrospective
Japan[15]	60	1,140,653	0.53	1996–2001	Prospective
Germany[16]	52	284,067	1.83	2003–2005	Retrospective
North America[17]	282	174,912	16.1	2010–2011	Retrospective
France[18]	146	683,171	0.21	2017–2018	Retrospective
Europe[19]	320	39,099	81.8	5 years	Retrospective

(DON). The occurrence of DCI has been linked to DON and recent studies have suggested technical divers are at greater risk than recreational divers due to repetitive, long, deep dives.[21–23]

Finnish technical divers not only perform challenging dives, they also do so in freezing cold conditions. This is especially emphasised during the winter months when there is a 'reverse thermocline' which results in the decompression being performed in even colder water than the constant 4°C water at the bottom depths. Surprisingly, cold was not the leading suggested contributing factor in this study. Perhaps Finnish divers are habitually accustomed to cold and therefore under-emphasise it in these arctic environments, despite cold being an important risk factor[24,25]

In this study, 11 DCI cases out of 27 occurred after multiple days of diving. Only two cases occurred after a training dive, and all the rest of the DCI cases occurred after deep dives. Typically, divers suggested tiredness and dehydration along with multiple days of diving as contributing factors in DCI. There are several studies suggesting that multi-day hyperbaric exposure might give a protective (acclimatising) effect on DCI and would lower the incidence.[26] Despite the possible acclimatisation, diving deep and very long dives multiple days in a row seemed to increase the incidence of DCI in this study.

LIMITATIONS

Our results depend on self-reported data, which introduces some limitations. Firstly, recall bias may exist even though this is a prospective study. Secondly, there is always a chance that divers unintentionally over-report or under-report the symptoms. There are no records of all technical divers in Finland using mixed breathing gases, and therefore only the ones known by researchers were contacted causing a sample selection bias.

We studied a limited number of highly specialised divers that performed a total of 2,983 dives. Therefore, the results should not be generalised to different types of diving and other diving locations. Sadly, the study period coincided with the COVID-19 pandemic, which considerably reduced the number of dives and especially diving trips abroad. Another factor that reduced the number of dives was that Ojamo, a very popular mine-diving site, was not available for most of the participating divers.

Conclusions

This online survey serves to better determine the incidence of DCI symptoms among Finnish technical divers. The overall incidence of DCI symptoms aligns with previous research using the same methodology. However, the incidence of reported DCI symptoms was 27 times higher than for HBO-treated DCI cases. Divers seem to readily recognise even the mildest DCI symptoms very well. Due to the low rate of FAO_2 utilisation in this study, there appears to be a need to improve divers' awareness and education of the importance of FAO_2. Furthermore, there is also a need to emphasise the importance of seeking contact with expert diving medicine advice in order to assess the severity of the symptoms and consider medical input.

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