Review article

Development of myopia in scuba diving and hyperbaric oxygen treatment: a case report and systematic review

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Abstract
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Introduction: A 54-year-old, previously healthy Caucasian male diver was on a 22-day liveaboard diving holiday. During this time, he performed 75 open-circuit dives, of which 72 were with enriched air nitrox. All dives were within recreational length and depth. After the trip he noticed a worsening of vision and his refraction had changed from the previous -3.75/–5.75 to -5.5/–7.75 dioptres. Hyperoxic myopia is a well-known phenomenon after hyperbaric oxygen treatment (HBOT), but related literature in recreational divers is scarce.
Methods: A systematic literature review on the effect of a hyperoxic environment on the development of myopia was done according to the PRISMA guidelines. Three databases were searched: Ovid MEDLINE, Scopus, and the Cochrane Library. A risk of bias analysis was done on all articles, and the GRADE approach was used to evaluate the quality of evidence. Articles that had sufficient data were used to synthesise a visualisation of oxygen exposure and changes in refraction.
Results: Twenty-two articles were included in this review. These included five case reports, two case series, nine cohort studies, one randomised controlled trial and five reviews, of which one was systematic. Most articles described HBOT patients' ocular complications, although four articles were diver centric. The synthesis of results suggests that divers tend to get a greater myopic shift with a smaller exposure. However, the data were too heterogeneous to perform meaningful statistical analyses. This review is the first to focus on divers instead of HBOT patients.
Conclusions: The case presented led to a systematic literature review on the effects of hyperbaric oxygen on refractive changes in both HBOT patients and divers. The data were too heterogeneous to make meaningful suggestions on a safety limit to prevent myopisation in diving.

Introduction

In recent decades, the use of enriched air nitrox (EAN) has become increasingly popular in the recreational diving community. Previously, such gas mixtures were only used by technical divers. However, due to its benefits in prolonging the bottom time and decreasing the nitrogen load during diving holidays, its popularity has grown, and it is, therefore, available nowadays at almost any dive centre. Unfortunately, human physiology is not adapted to a constant hyperoxic environment, and whereas EAN can make diving safer from a decompression stress perspective, it also predisposes to some less-discussed adverse effects of oxygen toxicity, such as possible myopia or the maturation of cataracts. This phenomenon is well known in hyperbaric medicine and, to some extent, in technical diving and occupational diving. Regardless, authors of this article are not aware of literature on myopia in purely recreational diving. Due to the increased use of EAN in recreational diving, it should be discussed in greater detail.

Myopia and cataracts are common eye pathologies that are well understood. The physiology of the eye changes when it is exposed to a hyperbaric environment and even more so when the partial pressure of oxygen increases. The effect this has on the lens has been previously studied in animal models.[1,2] The hyperoxic environment causes oxidative stress in the eye metabolism by oxidising glutathione, which leads to changes in the opacity of the lens, and thus contributes to the formation of cataracts.[3] Additionally, oxidative stress creates free oxygen radicals that damage the crystalline structures of the lens,[4] as well as other water-soluble proteins.[2] These are suggested to cause the refractive change in the lens, which then manifests as a shift towards myopia.[5] The myopic shift is suggested to be a precursor of the development of cataracts.[1]

The oxygen exposure limit leading to the ocular changes is not known. Divers are well acquainted with oxygen toxicity in terms of pulmonary toxicity and central nervous system toxicity. These are evidently more severe manifestations of the toxic effects of oxygen, as they may lead to convulsions, loss of consciousness, and, in an underwater setting, death.[6] The National Oceanographic and Atmospheric Administration (NOAA) has developed safety limits for divers to follow. Oxygen toxicity unit (OTU) and central nervous system percent (CNS%) scales were developed to estimate (respectively) the pulmonary and cerebral effects of hyperoxia.[6] These are taught to divers who want to use EAN during their dives.

In this paper, we report a case where the diver's myopia deteriorated during a diving vacation using primarily EAN as a breathing gas. The popularity of EAN in recreational diving has raised the question of whether it is needed on frequent but shallow dives. As this was not well described in the literature, a systematic review was performed to assess the effects of a hyperoxic environment on the development of myopia in divers and HBOT patients. The secondary objective was to compare the development of myopia in divers and HBOT patients to see how the case presented aligns with the literature.

Case description

Written informed consent for publication of his case was received.

A 54-year-old, previously healthy Caucasian male diver was on a 22-day liveaboard diving holiday. He performed 75 open-circuit dives on consecutive days. Of these, 72 were with enriched air nitrox 32% (EAN32) breathing gas and the remaining three with air. The daily number of dives was as follows: four dives/day for thirteen days, three dives/day for six days, two dives/day for two days and one dive/day for one day. The detailed dive log including the oxygen toxicity parameters was available only for the last 35 dives due to memory limitations of the old model dive computer (Suunto Vyper). The summary of the dives is shown in Table 1. Development of the daily central nervous system toxicity (CNS%) is shown in Figure 1, and oxygen toxicity units (OTU) in Figure 2. These were calculated by the diving computer for each dive using the NOAA rules,[6] which are commonly taught to divers. The cumulative CNS% calculations were slightly modified, as the a generic formula for half-life (Equation 1), was used instead of a less accurate constant half-life of 90 minutes.

$$N(t) = N_0 \left(\frac{1}{2}\right)^{\frac{t}{t_{1/2}}} \quad \text{Eq 1}$$

After the trip, he noticed that he had developed impaired vision and therefore visited an ophthalmologist. His refraction had changed from the previous -3.75/–5.75 dioptres evaluated two years earlier by an ophthalmologist, to -5.5/–7.75 dioptres. Before the trip he had not reported any new refractive problems. In addition, an ophthalmologist diagnosed early cataracts that were not seen previously. Other diseases, like diabetes and hypertension, were excluded. He had no history of ocular trauma, use of topical steroids or other ocular medications, nor exceptional exposure to sun. It was noted that he had suffered a retinal detachment twice in both eyes six- and seven-years prior that was adequately treated with no residual complications. During follow-up time of one month the refraction improved to -4.75/–7.00 but thereafter remained stable for six months, after which further improvement was not observed. During the following year the vision worsened to -5.25/–7.25 dioptres, even though the patient did not dive during that year. Subsequently he took a short diving holiday and dived 11 times over five days using air, not immediately noticing any difference in his vision. However, two months later an ophthalmologist measured his refraction at -6.00/-7.50 dioptres. There was no change in his cataracts.

Method

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed for the literature search and writing process. The PRISMA checklist is provided as a Supplementary file 1*. The protocol was registered on PROSPERO (CRD42023450396) before the analysis.

Table 1
Specifications of all the dives (n = 75) during the 22-day-long diving trip; msw – metres of seawater

Parameter	Dive time minutes	Maximum depth msw	Average depth msw
Mean	68	26	16
Median	68	27	17
Range	49–93	12–36	7–22

* Supplementary files 1–5 can be found on the DHM Journal website: https://www.dhmjournal.com/index.php/journals?id=345

Figure 1

Daily central nervous system percent oxygen exposure (CNS%) based on NOAA limits over the last 11 days of diving; the CNS% accumulated during the dive was recorded from the diving computer. The daily limit for CNS% is 80%, represented by the red line

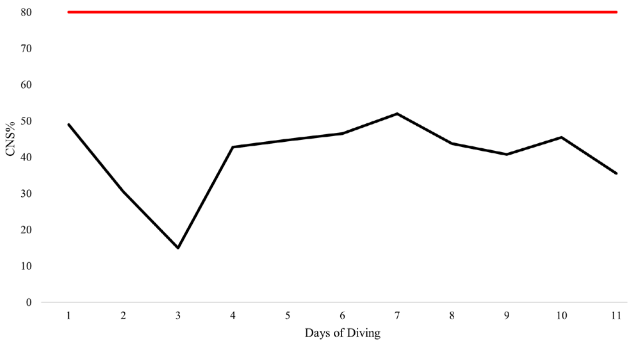
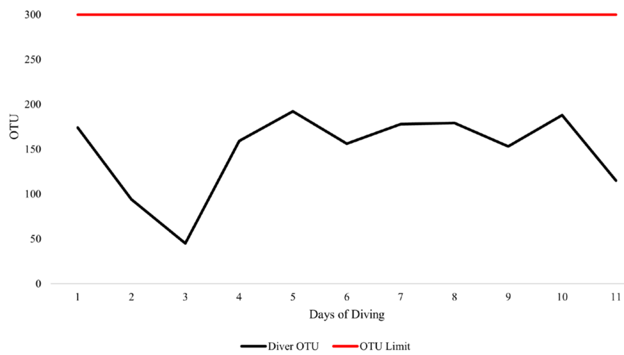


Figure 2

Diver's daily oxygen toxicity units (OTU) for the last 11 days of diving; the safety limit over nine days of diving is 300 OTU, which was respected throughout the diving vacation



SEARCH STRATEGY

The literature search was conducted on 3 October 2023, and the databases searched were Ovid MEDLINE, Scopus, and the Cochrane Library. The following search string was used:

((Myopia OR Myopic* OR Cataract* OR "*Vision chang**" OR "*Visual acuity*" OR "*Visual chang**") AND ("*Hyperbaric oxygenation*" OR "*Hyperbaric oxygen*" OR Diving OR Hyperoxia OR Hyperox* OR "*Oxygen* toxic**" OR "*Oxygen* poison**"))

The full search strategy can be found as a Supplementary file 2*. A medical librarian was consulted in the development of the search strategy and helped perform the final search. Two researchers (SS, ARS) went through the elimination process independently and any disagreements were discussed until a common understanding was reached.

ELIGIBILITY CRITERIA

Studies investigating the changes in refraction after exposure to hyperbaric and hyperoxic environments were sought. The scope of this review was on humans, so any non-human studies were excluded. However, there were no restrictions as to the age or sex of the patient populations. The only restriction in the health status of patients was an existing eye pathology before HBOT (e.g., vision loss due to arterial occlusion), as this was considered to be a confounding factor with the aim of this study. The hyperoxic environment was defined as HBOT or diving. Caisson workers were excluded. This study only involved peer reviewed and published work. Clinical articles, case studies, and reviews were all included, but expert opinions and commentaries were not. Additionally, only English works were included, and papers published before the year 1970 were excluded.

RISK OF BIAS AND CERTAINTY OF EVIDENCE

Joanna Briggs Institute (JBI) Critical Appraisal Tools[7] were used for each type of article separately (case study, case series, cohort study, systematic review, narrative review, randomised controlled trial). This tool consisted of a checklist including 8–13 questions that had "*yes*", "*no*", "*uncertain*", and "*not applicable*" options. It was used to assess the methodological quality of each study. This was done by analysing the possibility of bias in the study design, how the study was conducted and what analysis was used in each research article. The assessment was done at a study level, and any study failing to get a minimum of 50% of the total "*yes*" answers was excluded due to evident bias present in the article. The quality assessment was performed by two researchers independently (ARS, SS). The disagreements were discussed between the two researchers until a common understanding was found.

The certainty of evidence of each article was assessed using the grading of recommendations, assessment, development, and evaluation (GRADE) approach.[8] This approach takes into consideration whether a study is a controlled trial or an observational study and then upgrades or downgrades the quality of evidence based on study quality, imprecision, indirectness, inconsistencies, and effect size. This was done by three researchers, two of whom were working together (ARS, SS) and one independently (RVL). The results were discussed until all three agreed on the grading.

* Supplementary files 1–5 can be found on our website: https://www.dhmjournal.com/index.php/journals?id=345

SYNTHESIS OF RESULTS

Studies used for data synthesis must have clearly stated the oxygen exposure and the change of the refraction in dioptres. All studies failing to do so were excluded from the synthesis. The data including oxygen exposure, change in refraction, oxygen toxicity units, the pressure at which oxygen was breathed, the number of participants, and whether they were divers or HBOT patients were extracted. If the oxygen percentage used in HBOT was not specified, it was assumed to be 100%, and if 'air breaks' were not mentioned, it was assumed there were none. If the change in refraction was given separately for the left and right eye, the average change was calculated. The 'standard' HBOT treatment plan was assumed to be 90 min at 240 kPa of 100% oxygen. To make the oxygen exposures comparable between different studies, HBOT patients and divers, the oxygen exposure was calculated in hours of 100% oxygen exposure at one atmospheric pressure (101 kPa). These calculations apply exclusively to periods of diving or HBOT. The formula used is shown below:

> Exposure = number of treatments or dives x inspired fraction of oxygen x time (hours) x average pressure (atmospheres absolute)

These exposures were plotted against the refraction change in dioptres. All studies measuring only visual acuity or other measurements, such as intraocular pressure, eye axial length, or keratometry, etc. were excluded from the synthesis. Patients treated with HBOT were reported separately from divers. Additionally, the number of participants in each study was taken into consideration. The data extraction was done by one author (SS) under the supervision of the two senior authors (RVL, ARS). However, due to the observational nature of the study topic, no statistical tests were done, as they would not be meaningful and would bring very little additional value to the synthesis.

Results

Figure 3 shows the selection process as a flow chart. Initially, 478 records were identified; after the removal of duplicates 454 records were left for the screening process. After the initial screening of titles and abstracts, two researchers working independently (ARS, SS) agreed on 51 full text articles to be sought for retrieval and assessed against the eligibility criteria. Twelve articles could not be retrieved due to unavailability, leaving 39 articles to be assessed. After assessment another 16 full-text articles were excluded. Of these, 14 articles were excluded due to insufficient information on myopia developed in study subjects, i.e., a brief mention of ocular side effects without any further information as to the severity or reversibility was not considered sufficient. One article was excluded due to existing eye pathology (phakic and pseudophakic eyes) before HBOT. Finally, 23 articles met the inclusion criteria of the search. However, one article was later excluded due to acquiring less than 50% of the "*yes*" answers in the risk of bias assessment.[9] Thus, the final number or included articles was 22.

A total of five case reports[10–14] and two case series[15,16] met the inclusion criteria. The most frequent study design was a cohort study with nine articles meeting the criteria.[17–25] Finally, one randomised controlled trial met the criteria.[26] Additionally, five reviews met the criteria, four of which were narrative in nature[27–30] and one systematic.[31] The summary of the articles included is presented in Supplementary file 3* from which reviews are excluded.

RISK OF BIAS

Figure 4 represents the summary of risk of bias analysis using JBI Critical Appraisal Tools. Starting from the top, first the case reports are presented, followed by case series, cohort studies, randomised controlled trial, systematic review, and finally, the narrative reviews. Each study design had its own checklist. The results are presented as percentages. There were five articles that scored a full 100%, of which three were narrative reviews and two case reports. Additionally, six cohort studies only got "*yes*" and "*not applicable*" answers, similarly demonstrating a low risk of bias. The average percentage of "*yes*" answers was 80%.

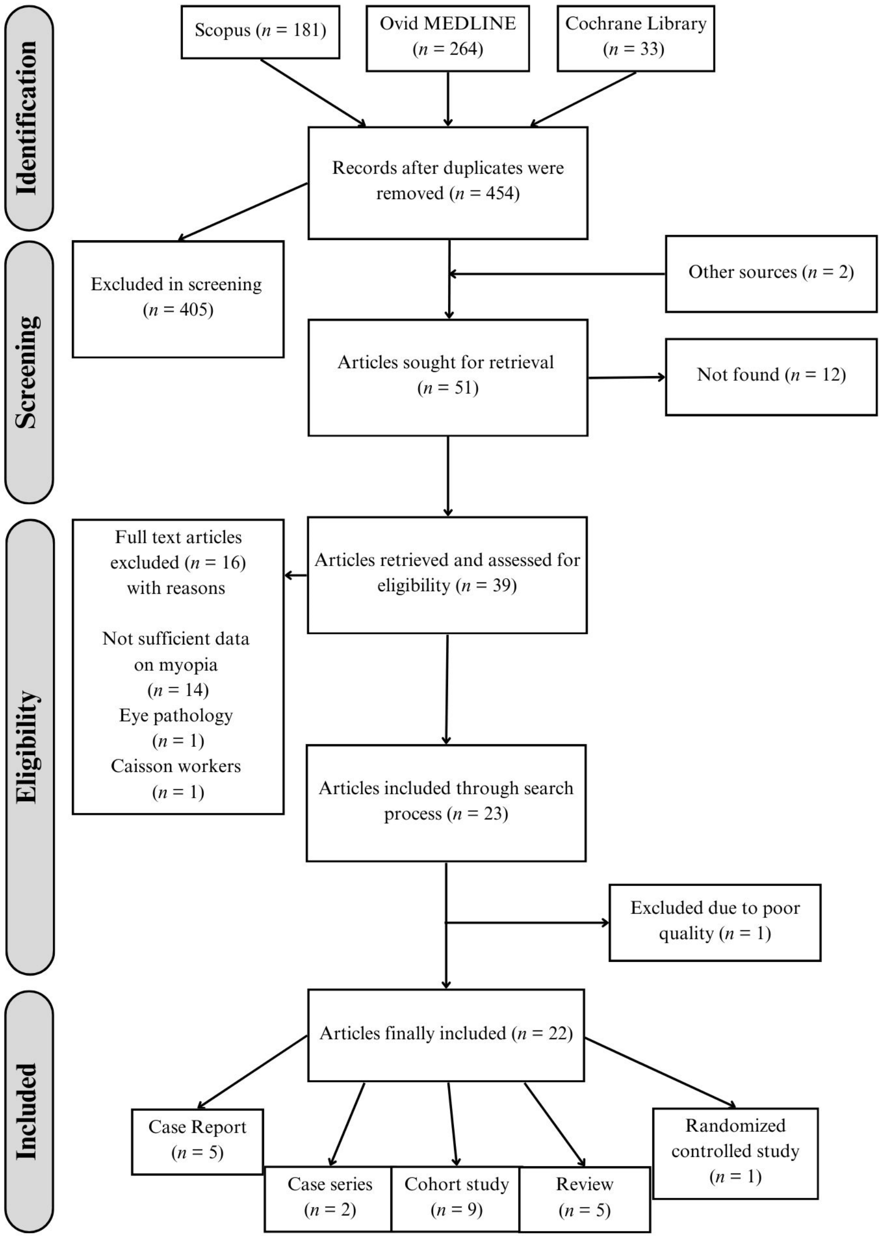
OCULAR CHANGES IN DIVERS

Only four articles described ocular changes in scuba divers including two case reports,[13,14] one case series[16] and one cohort study.[25] Marín-Martínez et al. presented two cases of occupational divers, both of whom complained of worsening vision after diving. One of them related this to a recent change to a closed-circuit rebreather (CCR). While there is a mention of use of HBOT after each dive, the reason for this treatment is unclear. It is also unclear what sort of dives they performed and how often, thus making it impossible to evaluate the oxygen exposure.[13]

Another case of hyperoxic myopia was reported by Butler et al. (1999). A 48-year-old male was participating in a film project requiring daily dives for 21 days. He was using a CCR with constant oxygen partial pressure of 130 kPa in an EAN mixture. He was exposed to a cumulative effect of hyperbaric oxygen during a total of 84.8 hours of diving at 130 kPa oxygen and started noticing a worsening of vision after 18 days. Once he had returned from his expedition, he was examined and found to have a myopic shift of -1.50 dioptres (D) in both eyes. After almost two months, his vision was restored and even turned slightly hypermetropic.[14]

* Supplementary files 1–5 can be found on our website: https://www.dhmjournal.com/index.php/journals?id=345

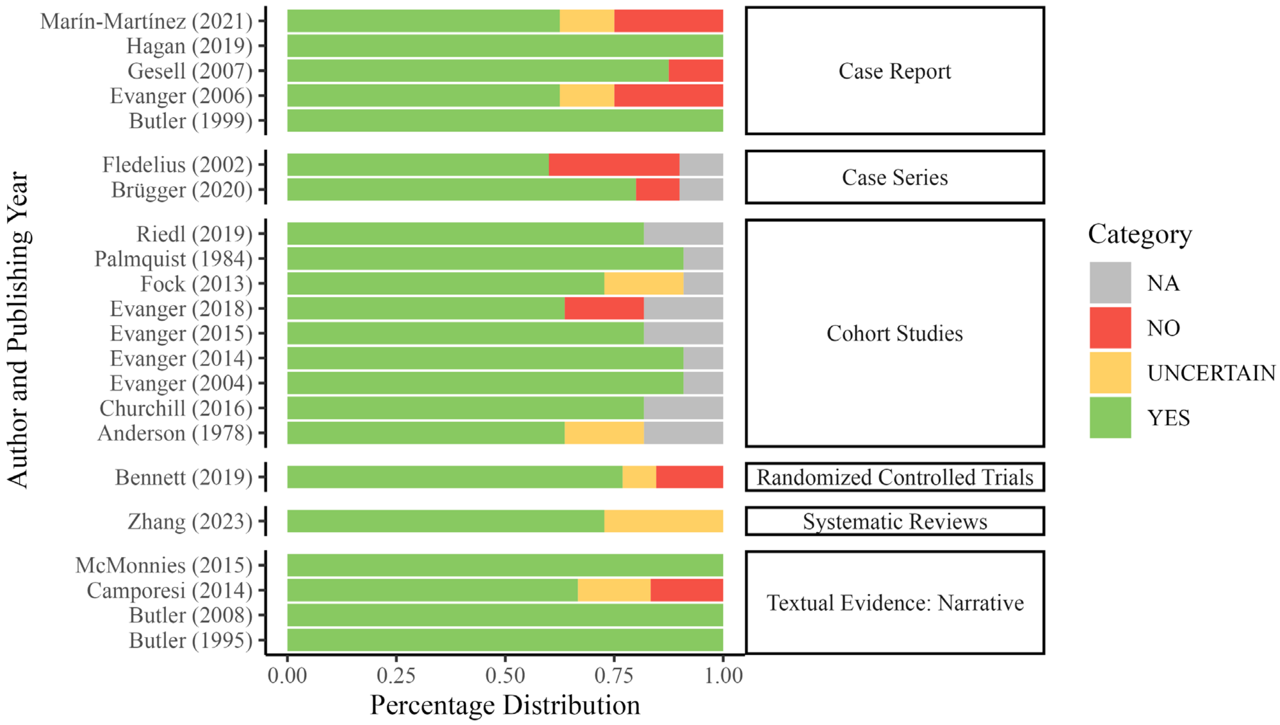
Figure 3
PRISMA flow diagram demonstrating the selection process of the articles for the systematic literature review



A case series of four military divers was presented by Brügger et al. (2020), wherein the subjects were exposed to 135 kPa of 100% oxygen via a MK20 Aga full-face mask with an open circuit regulator in a test pool. They were asked to perform light exercise on a bicycle for 30 minutes continuously every hour. Each dive was six hours long, and the participants dived for five consecutive days with an 18-hour surface interval in between dives; an equivalent exposure to 40.5 hours breathing 100% oxygen at 101 kPa. All subjects had an objective worsening of vision, measured with a Snellen chart, but recovered spontaneously seven to 30 days after onset.[16]

Finally, Fock et al. (2013) presented a cohort study with 14 male CCR divers and one OC diver who performed multiple day diving expeditions with an average of two dives per day, with a surface interval of approximately four hours between dives. The CCR divers maintained an oxygen partial pressure of 130–140 kPa for most of the dives. The mean duration of the dives was 112 minutes, and the average depth was 69 metres of seawater (msw). The mean change in visual acuity, reported in dioptres, was 0.4 on the 13th day of the expedition. Only one diver sought formal evaluation by an ophthalmologist, and his vision returned to baseline eight weeks after the expedition.[25]

Figure 4
The summary of risk of bias analysis



OCULAR CHANGES IN HBOT PATIENTS

The majority of the articles that met the inclusion criteria for this review were on HBOT patients. A total of three case reports,[10–12] one case series,[15] eight cohort studies,[17–24] and one randomised controlled trial[26] were included. The summary of the results is presented in Supplementary file 3*.

All three cases developed a significant (> -0.5 D) myopic shift after HBOT treatment. Two of the cases were female and one male. The age range was 49–58 years and the treatments varied from 21 to 48 treatments in total. All were treated with 90 min sessions at 200–240 kPa. All three subjects had their refraction measured, with the minimum myopic shift being -1.25 D, and the maximum -1.75 D. One patient's eyesight kept worsening, and at 11 months post-HBOT, the refraction in both eyes were measured -4.25 D.[10] Another patient developed hypermetropic shift four weeks after the completion of HBOT series. It continued worsening until 11 weeks after treatment, when the refraction was +1.62 D in the right eye and +1.50 D in the left eye. It remained stable at last follow at 1.5 years.[12]

In the Fledelius et al. (2002) case series, 17 patients were treated with HBOT, mostly for post-radiation osteonecrosis of the mandible. Patients with cataracts were excluded from this study, and all patients received 30 treatments of 95% O_2 at 250 kPa in 95 min sessions. The oxygen was delivered via a mask system. The patients' visual acuity, refraction, and keratometry were measured, and the median change of refraction was -0.62 D, however, there was no change in visual acuity.[15]

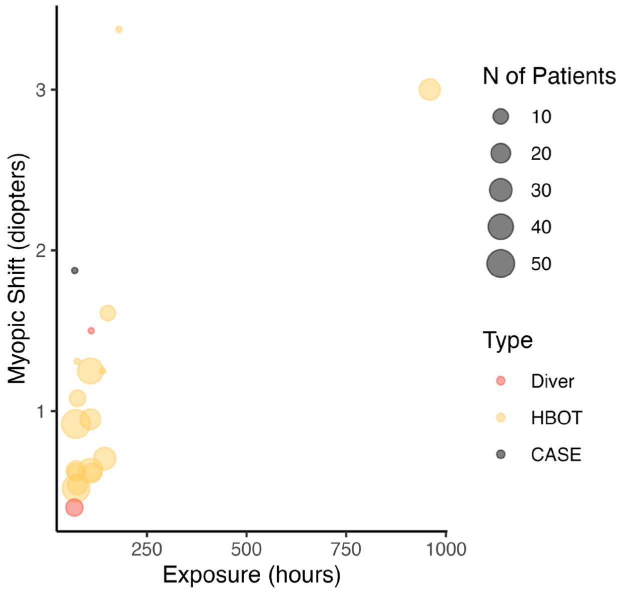
The cohort studies form a heterogenous group of articles with varying results. The most common indications for HBOT were osteoradionecrosis, persisting leg ulcers, osteomyelitis, proctitis, or cystitis, but some studies did not specify the indication of HBOT.[22,24] One study included only patients having HBOT for the first time, or less than 40 treatments and no cataract surgery.[20] The mean age of patients varied between 55.1 and 61.7 years. The total number of treatments varied from 10 to 425. Most commonly, the treatment time was 90 min, however, longer treatments were also used.[17,18] Some had breaks for breathing air during the treatment, whereas others did not. The oxygen percentage breathed was not always mentioned but seemed to vary between 95 and 100%. Treatments were mostly given from Monday to Friday, or consecutively with no break days in-between. The Snellen Chart was commonly used to measure visual acuity, but most studies also examined the refractive error. The precision and equipment used to examine the eyes varied greatly, as a few articles also included ophthalmological measurements, such as keratometry, intraocular pressure, axial length of the eye, retinal thickness, and corneal thickness. All studies reported some myopic shift. In some articles, only some patients were affected (e.g., 60%),[24] but in others, all patients were reported to have visual changes.

VISUAL CHANGES IN RELATION TO OXYGEN EXPOSURE

Figure 5 was extrapolated from the articles reviewed, in order to compare oxygen exposure and the development of myopia in those studies. Out of the 22 articles that met the inclusion criteria, 14 works presented sufficient information

Figure 5

Synthesis of data from 14 articles showing the oxygen exposure, as hours of 100% oxygen at 101 kPa and vision change; HBOT patients, divers, and the case are demonstrated in different colours. The size of the population is represented in the size of the data point



on the number of patients, exposure, and myopic shift (in dioptres) to be included in a graph of exposure (as 100% oxygen-hours at 101 kPa) against myopic shift (in dioptres). Figure 5 is composed of articles listed in Supplementary file 3* all of which meet the inclusion criteria stated in the methods section. Articles that compared different administration methods or number of treatments[23,26] were given multiple data points, where one data point represents one group of patients (e.g., oxygen administered via hood). Supplementary file 4*shows the calculated exposures for each of the articles included. The weighted average of exposure was 155 hours in HBOT patients and 71 hours in divers. The weighted average of myopic shift was 1.0 dioptre in HBOT patients and 0.6 dioptres in divers. In contrast, the case report described in this article has a high myopic shift (1.88 D) with a relatively low exposure (68.6 hours). The cumulative exposure of the diver is calculated using the values in Supplementary file 5*. No statistical analyses were performed as these data are from a heterogenous group of original articles consisting of small sample sizes.

REVIEWS

Four narrative reviews met the inclusion criteria.[27–30] These reviews included most of the articles referenced in our systematic review. Two of these were by Butler, the first one dating back to 1995. That extensive review's focus was on optics in diving, but the ophthalmological complications related to decompression sickness (DCS) or HBOT were discussed as well.[27] In his second review, Butler focused on the ophthalmological indications for, and ocular complications of HBOT, including myopia. This review from 2008 included a greater number of articles, some involving divers.[28] McMonnies' review (2015) mentioned myopia only in a few sentences, with the focus on cataracts, keratoconus, and age-related macular degeneration.[29] Camporesi's review (2014) presented the general side effects of HBOT, but ocular complications were discussed in detail,[30] with most of our review's HBOT-related articles included.

Only one systematic review detailed the ocular complications and other side effects of HBOT. It followed the PRISMA guidelines and found that patients who underwent HBOT were significantly more likely to have ocular side effects compared to either sham therapy or other conventional treatments.[31] Nevertheless, the ocular side effects were not specified, thus potentially including ophthalmological conditions other than myopia. Furthermore, the review included only randomised controlled trials, thus, most of the articles included in this study were excluded.

Discussion

To the best of our knowledge, this is the first systematic review with the main focus on myopia in both divers and HBOT patients, in contrast to narrative reviews which have been written previously on the ocular complications of a hyperoxic and hyperbaric environment, focusing on HBOT.[27–30] One of these reviews took divers into consideration.[28] The systematic review included focused on the side effects of HBOT. However, ocular complications were briefly discussed.[31] The principal finding of this review is that even though hyperoxic myopia is a well-known phenomenon, especially in HBOT, the current evidence is not strong enough to suggest a safety limit of oxygen exposure to prevent complications. Nonetheless, guideline changes could be appropriate in the future with prospective and mindful study research.

It seems that some are more sensitive to a hyperoxic and hyperbaric environment. This is evident from multiple case reports on the subject.[10–14] Such subjects appeared to develop quite significant myopia compared to the cohorts. This could partly be explained by the nature of a case report, which generally describes an unusual presentation.[32]

Diving could potentially cause a greater myopic shift than HBOT, as divers appeared to develop myopic shifts at lesser exposures to oxygen. It has been previously suggested that the effect of oxygen is greater when submerged than in a 'dry dive'.[33] However, the data presented in this review are not reliable enough to support such a conclusion. Additionally, the intensity of exposure was different between HBOT patients and divers. The maximum partial pressure of oxygen the divers were exposed to was 140 kPa during the dive, or

* Supplementary files 1–5 can be found on our website: https://www.dhmjournal.com/index.php/journals?id=345

160 kPa during a decompression stop.[34] In contrast, HBOT patients were often exposed to a partial pressure of oxygen of 240 kPa. While patients undergoing HBOT were mostly subject to only one treatment daily, divers were observed to perform multiple dives within a day. Therefore, divers seem to be exposed to lower partial pressures of oxygen compared to patients undergoing HBOT, albeit at a higher frequency. Evanger et al. (2018) reported an improvement in the myopic shift after weekend breaks, with HBOT administered only during the weekdays from Monday to Friday.[22] This potentially indicates that divers tend to develop more myopia with a smaller exposure due to the frequency of the exposures, leaving less time for recovery between dives.

As there is no evidence of myopic shift in recreational divers, except for our case presented in this study, it is also unclear if the type of diving influences the development of myopic shift. The literature presented in this review portrays technical divers[13,14,25] and military divers,[16] who performed longer or deeper dives compared to recreational divers. It is more common for recreational divers to have a higher frequency of diving, e.g., on a diving vacation, but the dives are often shallower. Nevertheless, our case showed a relatively large myopic shift, and whereas this could be only a peculiarity, recreational divers should be investigated in greater detail in the future to investigate if the phenomena described in our case report is common or not.

Finally, based on our findings, it could be beneficial to discuss if the current oxygen toxicity limits presented by NOAA, taught early in divers' careers, are still relevant. These limits were developed to prevent the toxic effects of oxygen in the central nervous system (CNS%) and lungs (OTU),[6] both of which are more adverse than myopia. Regardless, the loss of visual acuity can also be debilitating. Technical divers pass the daily OTU and CNS% limits on their longer dives without any adverse effects, whereas the subject in our case report, whilst well below the recommended limits, still developed severe myopia that has not yet completely reversed. When compared to divers from DAN Europe's database, which includes 2,629 open circuit dives over a 5-year period, our case report patient had a shallower mean maximum depth (25.9 msw vs 27.1 msw), but a longer mean dive time (68 min vs 46.4 min).[35] DAN Europe's database includes technical divers, which can somewhat skew the results. Lastly, it is possible that unknown concomitant factors contributed to the worsening of vision of the diver in our case report.

STRENGTHS AND LIMITATIONS

The search process for this review was extensive. By broadening the scope to both HBOT patients and divers, more articles could be included. Additionally, no limitations were asserted on the type of study, thus a variety of literature was identified from case studies to randomised controlled trials. As reviews were included as well, a comparison of the articles included in this review and previous reviews showed that the search strategy was successful. The search found all the relevant articles from previous reviews, along with newer publications. Additionally, for a small field like diving medicine, a total of 22 articles seems an adequate review of the existing literature.

Nonetheless, partially due to the observational nature of diving and hyperbaric medicine and partially due to a long-time span of the research included (over 50 years), the overall quality of data cannot be considered scientifically very high. Furthermore, there were variations in the methodology and follow up times, which made comparison between studies difficult. To make a visualisation of oxygen exposure and refraction changes, some articles had to be excluded and others simplified. This was due to the great variation amongst the articles, including in their study designs. Because of this, no statistical analyses were done, as this would not give meaningful results due to the variations in the methods.

A weighted average was used, as it takes into consideration the number of subjects involved in the study. Therefore, case studies that tend to have severe myopic shifts with small sample sizes would not skew the results inordinately. Alternatively, studies such as Plamquist et al. (1984)[18] that involved very high exposure of a relatively large cohort altered the weighted average. Since no statistical analyses were performed, this measurement was given to clarify the difference between divers and HBOT patients. It is not possible to infer a relationship between oxygen exposure and the myopic shift. Hopefully, this encourages further research to determine reliably if there is a difference in the tendency to develop myopia.

The risk of bias analysis was done using different checklists for each study design in contrast to most systematic reviews, where one tool is used for all articles. This method was chosen because most of the general risk of bias tools give the greatest value to randomised controlled trials, and any other study designs are given lower scores. Randomised controlled trials are quite rare in diving medicine, thus, a tool taking into consideration the study design seemed optimal. Consequently, the risk of bias analysis shown in Figure 4 solely represents the degree of bias of the study in its own category. As a result, a comparison between categories is misleading, as different assessment criteria were used for each design.

FUTURE ASPECTS

In summary, this review demonstrates that more research is needed on the effects of hyperbaric oxygen, especially in diving, on the development of myopia. A carefully planned prospective study would be best suited to get useful data. Two issues should be investigated before any safety limits are suggested to divers. Firstly, whether shorter duration, but more frequent dives at lower partial pressures of oxygen are more problematic in terms of myopisation than longer duration but less frequent dives at higher partial pressures. Secondly, more ophthalmological data should be recorded on recreational dives, as diving holidays are quite popular. Addressing these issues through well-designed research may contribute to the development of enhanced safety guidelines and limits on the use of EAN for dives less than 20 msw. This is especially with regard to the development of ocular complications in particular hyperoxic myopia.

Conclusions

A case of a recreational diver, who developed significant myopia after a diving holiday, led us to perform a systematic literature review on hyperoxic myopia. This is the first systematic review that takes into consideration both divers and HBOT patients, and focuses on the myopic shift after a hyperoxic environment. With the increased use of EAN as a breathing gas in recreational diving, a greater proportion of the diving population is exposed to a hyperoxic environment, with even higher exposure to oxygen than when diving with compressed air. Specifically, the use of EAN in more frequent, but shorter and shallower dives, is not well studied. Existing literature does not provide enough information for making any new safety limit suggestions to prevent myopisation. Consequently, more targeted research is needed to gain an improved appreciation of who is at risk, and at what level of exposure.

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