Increasing prevalence of vestibulo-cochlear decompression illness in Malta – an analysis of hyperbaric treatment data from 1987–2017

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Key words
Decompression sickness; Diving; Scuba; Recompression; Symptoms

Abstract
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Introduction: Scuba diving is a big part of the tourism sector in Malta, and all the cases of decompression illness (DCI) are treated within the single hyperbaric referral centre in the country.
Methods: This retrospective analysis reviews all the medical records of divers with DCI in Malta within the 30-year period between 1987 to 2017 who required recompression therapy with hyperbaric oxygen.
Results: There were 437 discrete cases of DCI managed with recompression therapy. Amongst DCI subtypes, the prevalence of musculo-skeletal DCI is decreasing, whereas that of vestibulo-cochlear DCI is increasing.
Conclusion: The increasing prevalence of vestibulo-cochlear DCI may be due to a change in diving practices in Malta.

Introduction

Malta is located in the middle of the Mediterranean Sea, with many dive sites peppered around the islands, from reefs shallower than 20 metres' sea water (msw), to wrecks as deep as 120 msw available for exploration and diving. It is well connected to the rest of the world, and with an increasing popularity of diving and ease of travel, coupled with clear water visibility and a warm temperate climate all year round, diving is an important sector of the tourism industry in Malta. There are currently 61 licensed diving schools under the remit of the licensing authority for the diving sector in Malta, the Malta Tourism Authority, and the dive schools are organised under the umbrella of the Professional Diving Schools Association. From an audit of the diving sector performed in 2015, approximately 140,000 dives by 35,000 individual divers were performed in 2015.[1] Of these 140,000 stated dives, 19 divers required recompression, giving an incidence rate of decompression illness (DCI) of 1.357 per 10,000 dives, which is close to the often-reported range of 0.41 to 3.11 per 10,000 dives incidence rate for DCI worldwide.[2,3] In an ideal scenario, an accurate denominator of total dives performed per year would be available, but this is, in most cases, never available due to logistical reasons.

The number of diving-related accidents is well documented, since there is an internal medical record registry of DCI requiring recompression with hyperbaric oxygen therapy within the single referral hyperbaric unit in Malta. This study will describe the cases requiring recompression between 1987 and 2017 within the only hyperbaric referral facility in Malta. For this geographic region, there are no similar studies published in the literature. It was the impression of one of the authors (SM) that over the 30 years of his practice of diving medicine in Malta, the prevalence of musculoskeletal decompression illness was decreasing, coupled with an apparent increase in vestibulocochlear decompression illness. We thus sought to collect and statistically analyse the dataset and see if this personal impression found support in the form of a statistically significant result.

Methods

The study was submitted for ethics review by the Health Research Ethics Committee of Stellenbosch University (ethics number: UEA-2018-7529) and approved after conforming to national and international ethics principles, codes and standards. A waiver of informed consent was granted by the ethics committee.

Figure 1
Age distribution of divers recompressed to manage DCI in Malta for the period 1987–2017 (n = 437)

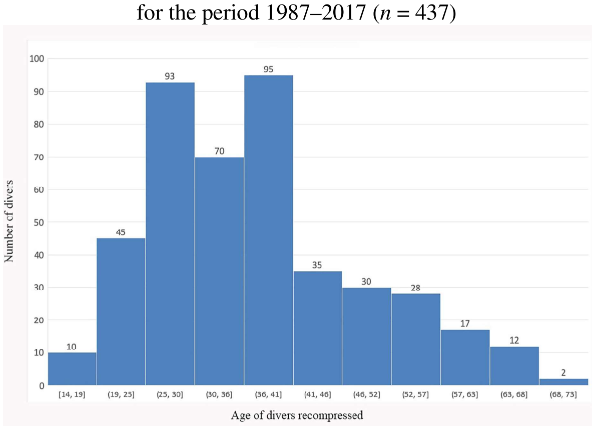


Figure 2
Choice of therapeutic table chosen in cases of divers recompressed to manage DCI in Malta for the period 1987–2017

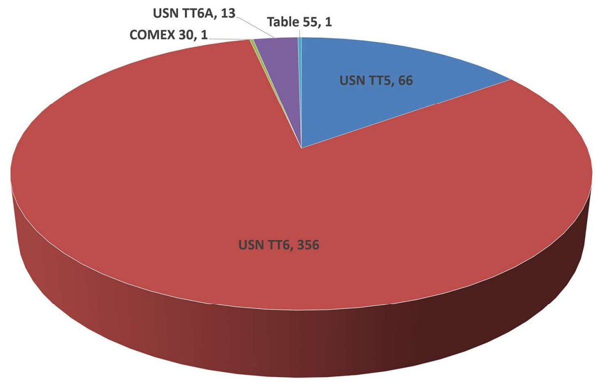


Figure 3
Sub-types of DCI in divers recompressed in Malta for the period 1987–2017. AGE = arterial gas embolism

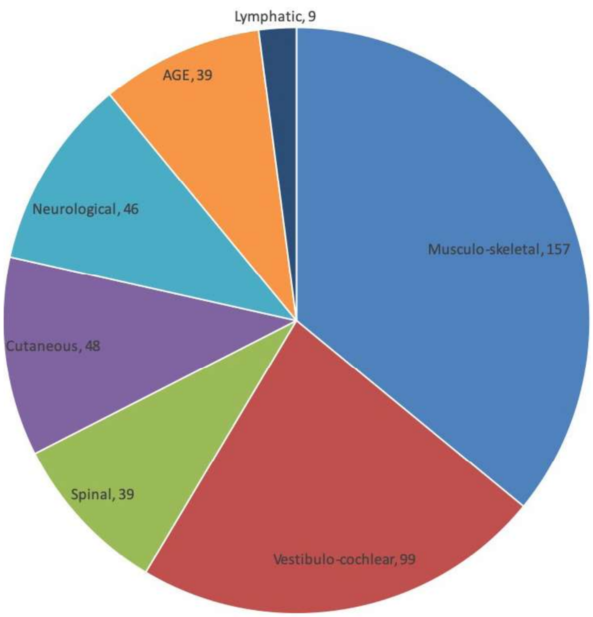
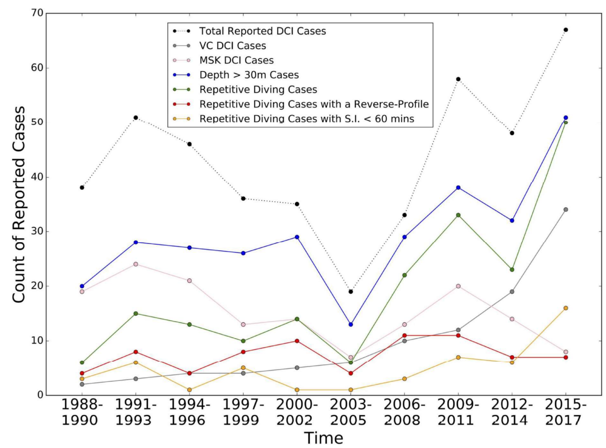


Figure 4
Trends in DCI cases 1988 to 2017. MSK = musculoskeletal. VC = vestibulocochelar



This study comprises an analysis of all the cases of DCI which were managed with recompression in the Maltese hyperbaric unit chambers between 1987 and 2017. The recompression chambers are situated within a tertiary care hospital; this was St Luke's Hospital between 1989 and 2007 and Mater Dei Hospital between 2008 and 2017. Prior to 1989, diving emergencies were treated in a Royal Navy recompression chamber manned by British military personnel present on the island until 1979, and the same chamber continued being used until 1994 by the physicians who took over from the Royal Navy (all these records have been included in the study). Scant written medical records exist prior to 1987. All records pertaining to the 1987–2017 period under analysis were captured.

STUDY POPULATION

The study sample consisted of all the divers who consulted the single referral hyperbaric centre during the 30-year study period and were managed with therapeutic recompression and hyperbaric oxygen for DCI. The term decompression illness has traditionally been used to refer to any medical illness arising as a result of lowering ambient pressure compared to a higher tissue gas pressure.[4] This includes decompression sickness (DCS) related to gas freed from solution in tissues during decompression, usually nitrogen or helium, and arterial gas embolism (AGE) caused by introduction of alveolar gas into the circulation leading to cerebral (most commonly) or coronary injury.

A patient was eligible for inclusion in the study if the written medical record file was identified as a result of a manual search of the paper medical records for all the years covering the study period, but if the consultation itself was not related

Table 1

Numbers of DCI cases, with musculoskeletal (MSK) and vestibulocochlear (VC) subtypes, for the period 1988–2017. Numbers of cases involving depth greater than 30 msw, repetitive diving, repetitive diving with a surface interval less than 60 minutes, and repetitive diving with reverse dive profiles are also shown. SI = surface interval between dives

Years	VC DCI	MSK DCI	Total cases	VC DCI fraction	MSK DCI fraction	Depth > 30 msw	Repetitive	SI < 60 min	Reverse profile
1988–1990	2	19	38	0.053	0.500	20	6	4	3
1991–1993	3	24	51	0.059	0.471	28	15	8	6
1994–1996	4	21	46	0.087	0.456	27	13	4	1
1997–1999	4	13	36	0.111	0.361	26	10	8	5
2000–2002	5	14	35	0.143	0.400	29	14	10	1
2003–2005	6	7	19	0.316	0.368	13	6	4	1
2006–2008	10	13	33	0.303	0.394	29	22	11	3
2009–2011	12	20	58	0.207	0.345	38	33	11	7
2012–2014	19	14	48	0.396	0.292	32	23	7	6
2015–2017	34	8	67	0.507	0.119	51	50	7	16

to diving medicine (e.g., a person undergoing therapeutic recompression for acute carbon monoxide poisoning or necrotizing fasciitis, or episodes of diving related barotrauma not involving the lungs), the file was excluded from the study.

VARIABLES

The following data were collected from the medical records: age, gender, DCI diagnosis and main organ system affected, the therapeutic table used, delay to treatment (beyond 60 minutes from development of first symptoms), treatment outcome, the depths of the dives performed on the day of the incident, the surface intervals between dives if multiple dives were performed, and whether repetitive (more than one dive per day) or reverse profile (shallow dive followed by a deeper dive) diving was performed.

STATISTICAL PROCEDURES

Linear regression analysis was used to assess the trend over time of musculoskeletal and vestibulocochlear DCI amongst all DCI subtypes. For the purpose of this analysis, the data were grouped in three-year bins, starting with 1988 (i.e., omitting 1987 data for the sole purpose of using uniform binning). The normal approximation to the binomial distribution was adopted to derive 1-sigma (i.e., 68%) binomial confidence intervals on the proportions of musculoskeletal DCI and vestibulocochlear DCI, and 1/variance weights were used for weighted least squares regression. An F-test was used to determine the model statistical significance, i.e., to test the null hypothesis that the gradient of the trend is zero, adopting a significance level of 0.05. Potential association of a given DCI subtype (musculoskeletal or vestibulocochlear) with dive variables (e.g., depth, repetitive diving, etc.) was analysed via a two-sided Fisher exact test, again adopting a significance level of 0.05. All quoted *P*-values are adjusted to account for multiple-testing. This was achieved via an adaptive two-stage linear step-up false discovery rate (FDR) controlling procedure.[5]

Results

There were 437 records identified for the study period. The age of the participants ranged between 14 and 71 years (Figure 1), with the mean age being 36(SD 11.64).

The gender distribution of divers with DCI was 78.5% male and 21.5% female. The distribution of choice of therapeutic table used for recompression can be seen in Figure 2, with

Figure 5

Linear regression analysis for the fraction of musculoskeletal DCI amongst DCI subtypes diagnosed in Malta for the period 1988–2017 presented in three-year bins. The confidence intervals represent the 1σ error, with the black, solid line representing the inverse variance-weighted fit. Adjusted $R^2 = 0.791$

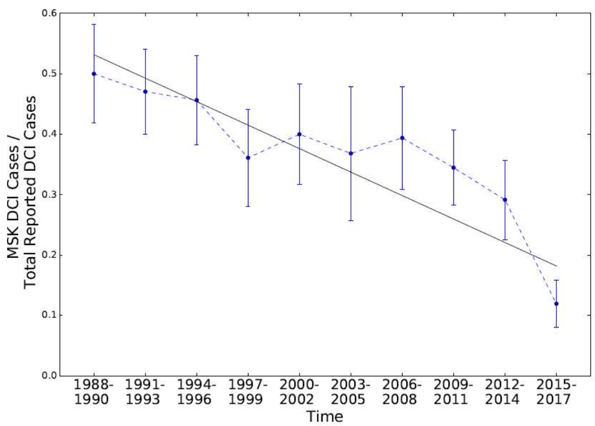


Figure 6

Linear regression analysis for the fraction of vestibulo-cochlear DCI amongst DCI subtypes diagnosed in Malta for the period 1988–2017 presented in three year-bins. The confidence intervals represent the 1σ error, with the black, solid line representing the inverse variance-weighted fit. Adjusted $R^2 = 0.836$

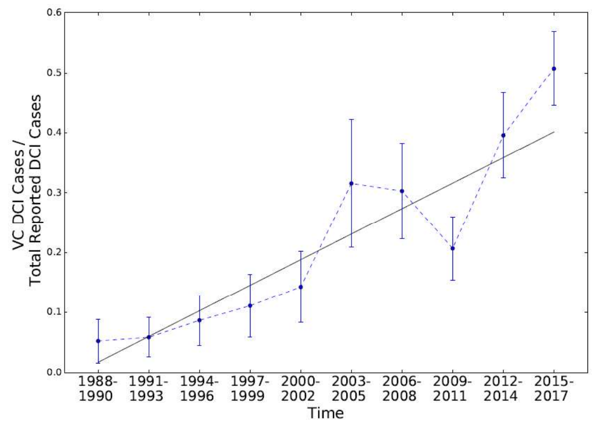
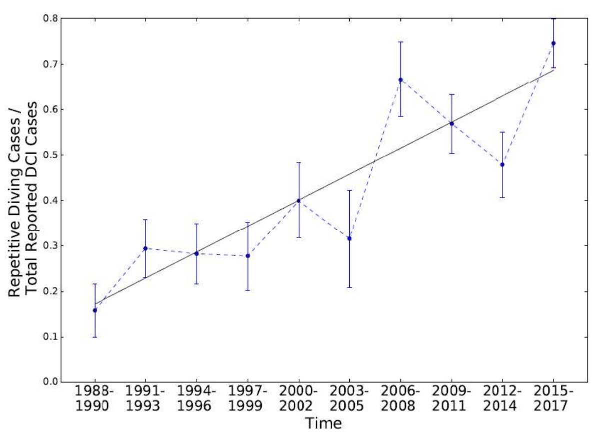


Figure 7

Linear regression analysis for the fraction of repetitive diving cases amongst total reported DCI cases diagnosed in Malta for the period 1988–2017 presented in three year-bins. The confidence intervals represent the 1σ error, with the black, solid line representing the inverse variance-weighted fit. Adjusted $R^2 = 0.832$



US Navy Treatment Table 6 being the most prevalent therapeutic table in use, while Figure 3 shows the subtypes of DCI recompressed inside the chamber during the 30-year period under investigation.

Table 1 shows the counts of musculoskeletal DCI or vestibulocochlear DCI subtypes diagnosed over the same period presented in three-year bins, together with the documented variables pertaining to each time-bin. These same data are also displayed graphically in Figure 4 for the period between 1988 and 2017. Vestibulocochlear DCI is fast becoming more commonly diagnosed amongst the various DCI subtypes.

Linear regression analysis of the fraction of musculoskeletal DCI amongst all DCI subtypes shows a statistically significant decrease over the study period ($P = 0.00037$), whereas the same analysis shows a statistically significant increase in the prevalence of vestibulocochlear DCI ($P = 0.00023$), as is shown in Figures 5 and 6 respectively. A statistically significant increasing trend ($P = 0.00023$) was also found for the fraction of cases that involved repetitive diving, as shown in Figure 7.

A two-sided Fisher exact test was employed to investigate association between a given DCI type (musculoskeletal or vestibulocochlear) and a number of dive variables, namely (1) depth (deeper than 30 msw), (2) repetitive diving, (3) reverse-profile diving (in the case of repetitive diving), and (4) a short (< 60 mins) surface interval (in the case of repetitive diving). Significantly greater proportions of dives > 30 msw (OR = 2.12, $P = 0.01614$), repetitive dives (OR = 2.74, $P = 0.00013$), and repetitive dives with reverse profiles (OR = 2.13, $P = 0.04205$) resulted in vestibulocochlear DCI. These comparisons are shown in Figures 8–10. No other associations were significant.

Discussion

Vestibulocochlear DCI typically presents with vestibular symptoms (ataxia, nausea, vomiting and vertigo), variably associated with cochlear symptoms (hearing loss and tinnitus) in two distinct situations; either during decompression from deep dives, with first symptoms developing in-water, or on surfacing from recreational open circuit compressed air dives, typically within the first 30 minutes.[6] The differential diagnosis between inner ear barotrauma and vestibulocochlear DCI (also termed inner ear DCS) is notorious in diving medicine for the difficulty it may

Figure 8
Proportions of cases with vestibulocochlear DCI who were diving less than 30 msw vs 30 msw or greater. Error bars represent 95% Wilson Score confidence intervals

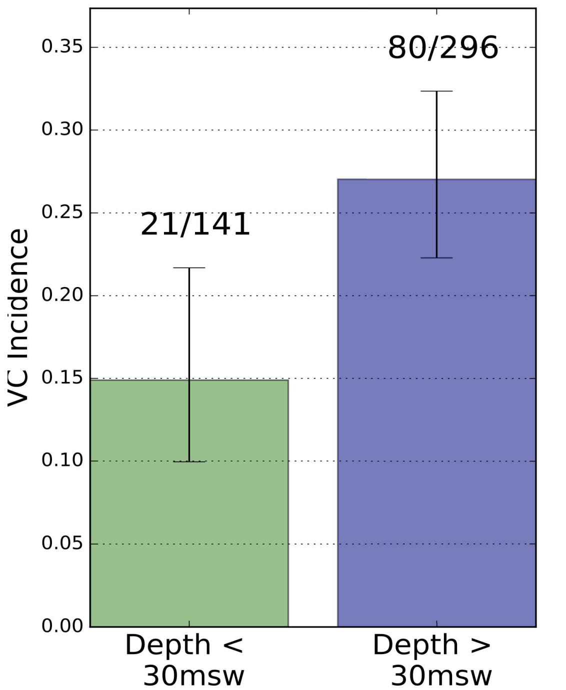


Figure 9
Proportions of cases with vestibulocochlear DCI who were performing single vs repetitive dives. Error bars represent 95% Wilson Score confidence intervals

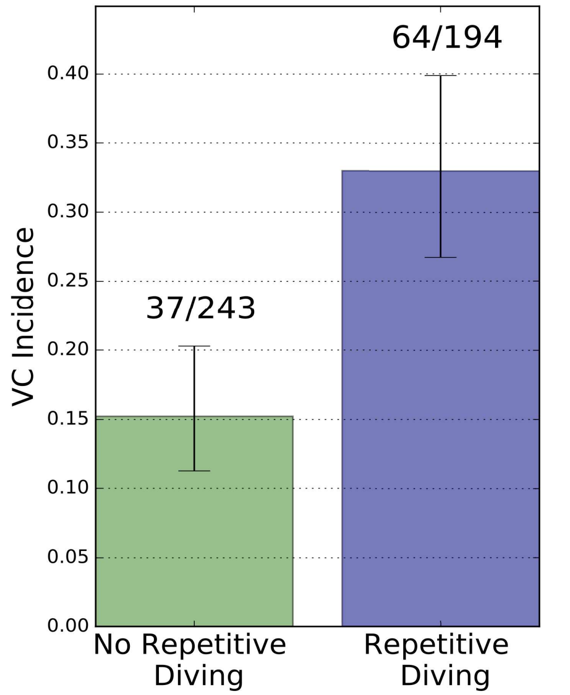
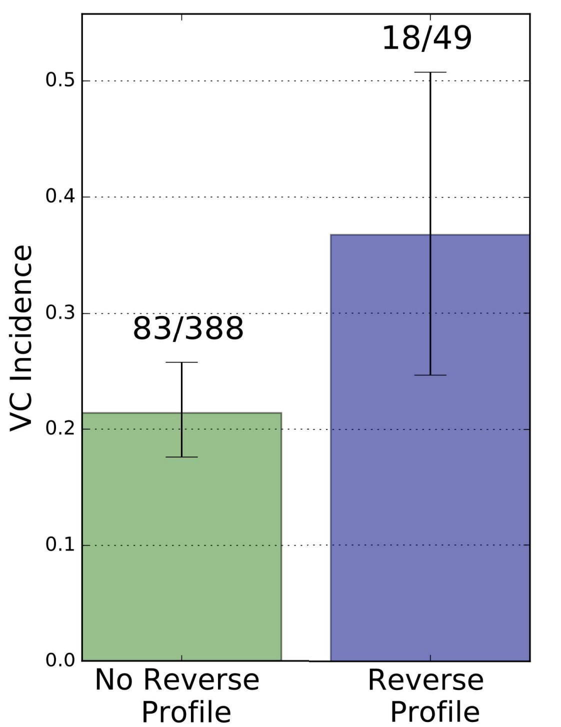


Figure 10
Proportions of cases with vestibulocochlear DCI who were diving reverse vs non-reverse profiles. Error bars represent 95% Wilson Score confidence intervals



present – inner ear barotrauma typically occurs during descent and is associated with difficulty equalizing the middle ear air space, with possible signs of middle-ear barotrauma on examination. In contrast, vestibulocochlear DCS typically presents either on ascent during decompression from deep helium dives, particularly after switches to nitrogen-containing mixes, or within 30 minutes of surfacing.[7] The difficulty also ensues at the treatment stage; the treatment of choice for vestibulo-cochlear DCS is recompression, whereas recompression is contra-indicated in cases of inner ear barotrauma.[7]

Vestibulocochlear DCI was classically described as a sub-type prevalent in mixed gas divers diving on breathing gas mixes containing helium, although it is becoming more commonly reported in recreational open circuit compressed air diving.[8–10] The pathophysiological mechanism of vestibulocochlear DCI, namely potentiation of arterialized venous gas emboli by inner ear supersaturation, especially in the setting of a right-to-left shunt such as a persistent (patent) foramen ovale, has been more recently delineated.[11,12] Our analysis shows that in Malta, vestibulocochlear DCI is associated with deep (> 30 msw) diving, repetitive diving, and reverse-profile diving.

This study provides evidence of evolving patterns of presentation in Malta over a 30 year period, influenced by the type of diving being performed. Between 1987 and 2000, the majority of DCI cases requiring recompression involved fisherman divers using SCUBA, a practice which was outlawed in 2000 during European Union accession talks. The steady rise of vestibulocochlear DCI over the years means that it has recently become the most prevalent subtype of DCI diagnosed in divers in Malta requiring recompression, possibly due to the diving sector having moved towards repetitive and deeper recreational diving in the 20 to 40 msw range.

We acknowledge several limitations of the study. The data were extracted from the hyperbaric centre medical records and were dependent on all diving medicine physicians being diligent in their documentation; bias could be present. Data were collected from all available notes, but this does not exclude the possibly there were cases which should have been referred for therapeutic recompression, but which were managed with normobaric oxygen on-site or treated with in-water recompression by the divers themselves. Finally, it would be very desirable to have a reliable audit of the total number of dives performed per year, as this would allow a more robust analysis. However, this is rarely available due to logistical reasons. The only audit of the Maltese diving industry that is available to us pertains to a single year (2015), as described in the introduction.

Conclusions

This study was performed in order to analyse the diving population presenting to the hyperbaric chamber team, and which ended up being diagnosed as DCI and undergoing recompression therapy. We found that there is a statistically significant reduction in the fraction of musculoskeletal DCI amongst DCI subtypes diagnosed, with the same analysis showing an increasing trend for vestibulocochlear DCI. We also found a statistically significant rising trend of cases involving repetitive diving. In the case of vestibulocochlear DCI, a statistically significant association was found with deep diving, repetitive diving and reverse profile diving.

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