Divers treated in Townsville, Australia: worse symptoms lead to poorer outcomes

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Abstract
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Introduction: Hyperbaric oxygen treatment (HBOT) is considered definitive treatment for decompression illness. Delay to HBOT may be due to dive site remoteness and limited facility availability. Review of cases may help identify factors contributing to clinical outcomes.
Methods: Injured divers treated in Townsville from November 2003 through December 2018 were identified. Information on demographics, initial disease severity, time to symptom onset post-dive, time to pre-HBOT oxygen therapy (in-water recompression or normobaric), time to HBOT, and clinical outcome was reviewed. Data were reported as median (interquartile range [IQR]) with Kruskal-Wallis and chi-square tests used to evaluate group differences. Significance was accepted at $P < 0.05$.
Results: A total of 306 divers (184 males, 122 females) were included with a median age of 29 (IQR 24, 35) years. Most divers had mild initial disease severity ($n = 216$, 70%). Time to symptom onset was 60 (10, 360) min, time to pre-HBOT oxygen therapy was 4:00 (00:30, 24:27) h:min, and time to start of HBOT was 38:51 (22:11, 69:15) h:min. Most divers (93%) had a good (no residual or minor residual symptoms) outcome and no treated diver died. Higher initial disease severity was significantly associated with shorter times to symptom onset, oxygen therapy, and HBOT, and with worse outcomes. The paucity of cases receiving HBOT with minimal delay precluded meaningful evaluation of the effect of delay to HBOT.
Conclusions: Most divers had mild initial disease severity and a good outcome. Higher initial disease severity accelerated the speed of care obtained and was the only factor associated with poorer outcome.

Introduction

The Great Barrier Reef (GBR) is one of the most popular places to dive in Australia. It is the largest living structure on the planet and extends for 2,300 kilometres along the Queensland coastline. With 2.4 million visitor days per year, the GBR provides 64,000 jobs and contributes $6.4 billion to the Australian economy in annual revenue.[1] Diving is a relatively safe sport, but 483 fatalities were reported with the activity in Australia from 1970 to 2018, 116 in Queensland.[2] Although death is relatively rare from diving, many divers are injured each year requiring treatment in a hyperbaric facility. In 2018, 112 divers were treated for decompression illness (DCI) in Australia, 34 in Queensland (Hyperbaric Technicians and Nurses Association, unpublished data). Decompression illness is a collective term embracing decompression sickness (DCS) caused by bubble formation from dissolved gas, and arterial gas embolism (AGE) caused by pulmonary barotrauma.[3] In this paper 'DCS' is used when the goal is to specifically refer to the consequences of bubble formation from dissolved gas, and the collective term 'DCI' is used to refer to both DCS and AGE.

Hyperbaric oxygen treatment (HBOT) is currently considered the definitive treatment for DCI.[3,4] Access to HBOT may be delayed due to the remoteness of a dive site and limited access to hyperbaric chambers. Delay to HBOT greater than three hours has been associated with poorer outcomes in severely injured divers.[5] The Townsville University Hospital operates the only hyperbaric chamber in north Queensland, providing physician advice and HBOT for injured divers from the Whitsunday Islands north to the Torres Strait as well as for divers from some of the surrounding Pacific Islands. However, no recent literature has been published on injured divers in north Queensland.

The aim of this retrospective review was to outline the incidence, care and outcome of injured divers referred to Townsville University Hospital hyperbaric medicine unit.

Methods

Ethics approval was granted from the Townsville Hospital and Health Service (LNR/2019/QTHS/51229) and James Cook University (H7767). The Townsville Hospital relocated to its current site in October 2001, with the installation of a new multi-place rectangular chamber (Fink Engineering Pty Inc., Warana, Queensland, Australia). Data from the first two years of service at the new site were presented at a diving medicine workshop.[6] This retrospective review includes all injured divers treated at the Townsville hyperbaric unit after the previous report, from 4 November 2003 through 31 December 2018. Yearly patient logs and electronic discharged summaries were reviewed to identify cases for inclusion.

Retrieval Services Queensland databases (Queensland neonatal emergency transport service, clinical coordination retrieval information system, and Brolga) were searched using key words and relevant diagnoses (cerebral arterial gas embolism, decompression [including illness and sickness], drown*, snorkel*, and scuba), hyperbaric med*, and offshore retrievals by rotary wing asset to identify cases. Identifying data (name, date of birth, and date of incident) were collected so that cases could be linked with hyperbaric unit data to ensure that no cases were missed or duplicated.

Individual charts were reviewed, and data extracted to pre-formatted forms. Where available, the Queensland state-wide diver injury assessment form provided valuable information (Appendix A [#]). Diver age, sex, region of origin, body habitus, medical history and known medication use was collected. Body habitus was classified using body mass index if height and weight data were available otherwise from clinical descriptions in the medical charts, passport photos, or staff memory. Diving history including qualification, reported number of previous dives, years of diving, previous DCI as well as a description of the incident dive (day of week, month, and place of incident, nature of the dive, dive team, breathing gas and circuit type, dive computer use, potential contributing factors, maximum depth, and total dive time) and symptom profile were obtained from medical records and dive logs. Due to the complexity of dive profiles and the lack of dive computer downloads, only maximum depth, and total dive time (also known as surface-to-surface or run time) were documented. If a dive log had depths recorded as fractions of a metre (e.g., 24.3 m) it was recorded that a dive computer had been used. Time of symptom onset was defined in two ways. First, using a binary definition: during the dive (symptom onset underwater during the dive) or post-dive (after arriving at the surface). Second, calculating an actual time duration from the time the injured diver arrived at the surface after the incident dive to the time of symptom onset. Due to the unavailability of details on time to symptom onset underwater, the time of arrival at the surface was used as the starting time point for calculating time to treatment for all divers.

Initial disease grade was classified as mild, moderate, or severe using a system developed in Townsville (Table 1).[6] This grading system is subtly different to the widely accepted paradigm that arose from the 2005 remote DCI workshop,[3] but it was adopted here for having been applied to the Townsville patients in 'real time' over the study period. Treatment details were collected including time to commencement of pre-HBOT oxygen therapy (if administered) after symptom onset.

Retrieval details were collected including platform (boat, rotary wing, fixed wing, or road) and type of retrieval (primary, secondary, or tertiary). Primary retrievals were classified as retrievals from a pre-hospital location. If a dive boat called for medical advice and was directed to return to shore, this was classified as a primary retrieval by boat. If the dive boat returned to shore without any urgency after completing their trip, this was not considered a retrieval. Secondary retrievals were defined as retrievals from a place of medical care to a second facility providing higher care. This may be a second retrieval leg after a primary retrieval or the transfer between two health care facilities after diver self-presentation. Tertiary retrievals were defined as transfers from a secondary site to a third facility. Road retrievals included ambulance, bus, or car. Time to start of HBOT following symptom onset, final diagnosis, and clinical outcome at completion of HBOT (characterised as in Table 2)[7] were determined.

[#] Appendix A can be found on the DHM Journal website: https://www.dhmjournal.com/index.php/journals?id=344

Table 1
Initial disease severity grade using the established Townsville Hospital categories;[6] mild and moderate symptoms are invariably decompression sickness (DCS) while arterial gas embolism events would be classified as severe

Severity	Definition
Mild	Symptomatic DCS with no objective signs except: Minor skin rash Lymphatic DCS Sharpened Romberg test less than 30 seconds
Moderate	Symptomatic DCS with subtle signs: Impaired higher function Impaired Romberg test Subjective sensory changes Minor weakness due to pain Cutis marmorata
Severe	Symptoms threatening life or mobility: Loss of consciousness Cardiopulmonary DCS Spinal DCS

Table 2
Clinical outcome classification at the end of hyperbaric oxygen treatment[7]

Well, no residual signs or symptoms
Minor symptoms, no functional significance
Residual symptoms, moderate impairment
Major incapacity
Dead

Two researchers (DB and RT) performed the data extraction. Forms were compared and consensus reached. Individual Retrieval Services Queensland records were accessed to clarify retrieval information not apparent in the hospital medical records. All collected data were de-identified and entered into an Excel worksheet, and subsequently exported into Statistical Package for the Social Sciences version 28.0.0 (SPSS®, IBM® Corporation, Armonk, New York, USA) for analysis.

ANALYSIS

Data are presented using frequencies and percentages for categorical variables, and median and interquartile range (IQR) for continuous variables as all data were not normally distributed as assessed using the Shapiro-Wilk test. The Mann-Whitney U test was used for analysis comparing time to symptom onset, oxygen commencement, and HBOT between divers with onset of symptoms at depth versus onset of symptoms after the dive. Comparison of initial disease grade with time to event data (symptom onset, oxygen delivery, and HBOT) and oxygen duration was completed using the Kruskal-Wallis test for analysis. Dunn's test was used for *post hoc* analysis with Bonferroni correction. Statistical significance was accepted at $P < 0.05$ for all tests. As data were missing from some medical records, the *n* presented throughout the results denotes the number of records for which the information was documented.

Figure 1
Number of injured divers by sex presenting for hyperbaric oxygen therapy at the Townsville hyperbaric medicine unit per calendar year during the study period 4 November 2003 through 31 December 2018

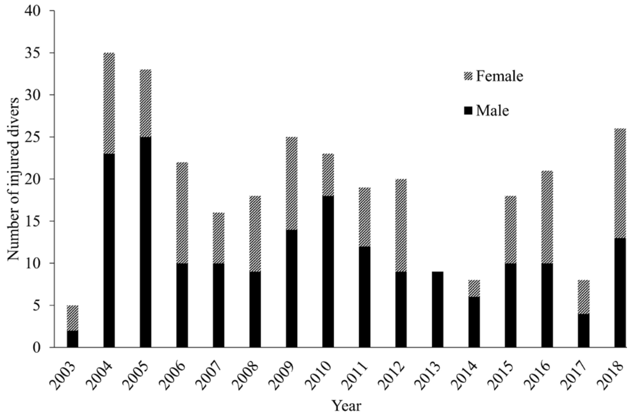
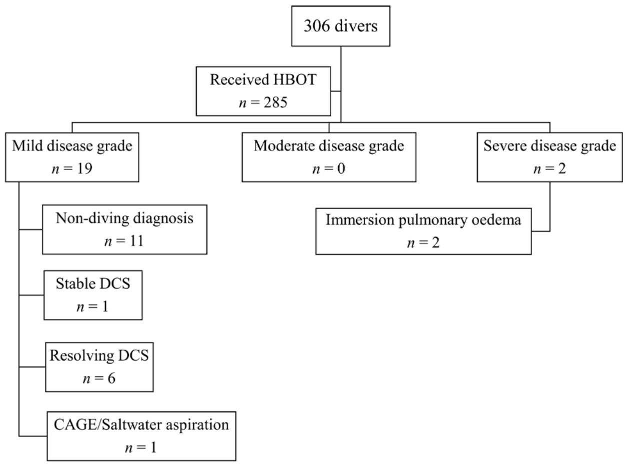


Figure 2
Breakdown of cases by initial disease grade of divers who did not receive hyperbaric oxygen treatment (HBOT); CAGE – cerebral arterial gas embolism; DCS – decompression sickness



Results

DIVER DEMOGRAPHICS

A total of 310 injured divers were identified during the study period. Four divers were excluded as their paper medical records had been destroyed following national medical record guidelines, one in 2003 and three in 2004, leaving

Table 3
Injured diver characteristics; data are *n* (%) unless otherwise specified; [a]World Health Organization regions; *n* = number of divers for which the data was documented in each category; DCI – decompression illness; IQR – interquartile range

Characteristic (*n* = 306)	
Male	184 (60)
Female	122 (40)
Median age (years)	29 (IQR 24, 35) (Range 14–74)
Region of origin[a] (*n* = 306)	
Western Pacific	159 (52)
Australia	143 (47)
Europe	103 (34)
Americas	43 (14)
Africa	1 (< 1)
Eastern Mediterranean	0
South-east Asia	0
Body habitus (*n* = 165)	
Underweight	5 (3)
Normal	135 (82)
Overweight	14 (8)
Obese	11 (7)
Relevant medical history	
Medical/Surgical history = yes (*n* = 292)	148 (48)
Medication use = yes (*n* = 248)	107 (43)
Diving qualification (*n* = 216)	
Uncertified	19 (9)
Student	25 (12)
Open water	57 (26)
Advanced	19 (9)
Rescue	13 (6)
Divemaster/Assistant instructor	16 (7)
Instructor	47 (22)
Commercial/Military	20 (9)
Relevant diving history	
Median number of previous dives (*n* = 198)	55 (IQR 9, 325) (Range 0–17,000)
Median years of diving (*n* = 75)	8 (IQR 2, 13) (Range 0–53)
Previous DCI = yes (*n* = 207)	41 (20)

306 divers for the analysis, displayed by year and sex in Figure 1. The term 'injured divers' is used intentionally to reflect the fact that some divers did not receive HBOT and had diagnoses other than DCI including cases considered to be suffering severe symptoms arising from immersion pulmonary oedema. (Figure 2). Most of the divers were from overseas, young, and certified with a wide range of reported previous diving experience (Table 3). Over half were male and the majority were of normal body habitus. A small number of divers reported having a previous incident of DCI (Table 3). Just under half of the divers had a history of a medical or surgical condition and many used a medication (acute or chronic) in the 48 hours before or after the incident dive (Table 3).

INCIDENT DIVE AND CONTRIBUTING FACTORS

Most incidents occurred during recreational dives (Table 4), during the summer (Southern Hemisphere) months, and on weekends (Friday through Sunday). Less than one-third of the incidents were in occupational divers and incidents were rare in scientific divers (Table 4). Just over half of the divers were diving with a buddy and the vast majority were breathing compressed air with open-circuit equipment. Only

Table 4
Incident dive characteristics; *n* = number of divers for which the data was documented

Characteristic	*n* (%)
Nature of dive (*n* = 260)	
Introductory	16 (6)
Certification course	55 (21)
Recreational	116 (45)
Occupational	69 (27)
Scientific	4 (1)
Technical	0
Dive team (*n* = 130)	
Solo	5 (4)
Buddy	68 (52)
Threesome	2 (1)
Group > 3	41 (32)
Surface support	14 (11)
Breathing gas (*n* = 177)	
Air	164 (93)
Nitrox 32%	6 (3)
Nitrox other %	6 (3)
Oxygen	1 (< 1)
Breathing circuit (*n* = 181)	
Open	158 (88)
Surface supply	22 (12)
Freediving	1 (< 1)
Dive computer (*n* = 160)	
Computer used	133 (83)

half of the medical records had documentation of whether a dive computer was used. In those with documentation, the majority used a computer (Table 4). The maximum dive depth recorded in 301 cases ranged from 1.8 to 50 metres of seawater (msw) (median 18, IQR 14, 25 msw). The total dive time recorded in 279 cases ranged from one to 210 minutes (min) (median 37, IQR 29, 45 min). Medical record documentation was poor for pre/post-dive contributing factors. However, dehydration and seasickness were commonly noted in those charts with documentation (Table 5). Possible contributing factors were varied, with repetitive dives and inadequate surface interval being the most frequently reported (Table 5).

SYMPTOMS AND TREATMENT AT SCENE

Most symptoms commenced after the incident dive (*n* = 275, 90%) rather than during the dive. The diagnoses of the divers with symptom onset during the dive were: 17 DCS, 10 cerebral AGE, one inner ear barotrauma and three immersion pulmonary oedema. All divers diagnosed with DCS had performed multiple dives often over several days. The median time to symptom onset post-dive (*n* = 269) was 1 hour (IQR 0:10, 6:00 h:min). One extreme outlier was identified. This diver had a time to symptom onset of 384 h. This diver was exposed to altitude by flying after diving, so the diagnosis of DCS was considered plausible, and the diver was recompressed, but the final diagnosis was

Table 5
Possible contributing factors for decompression illness pre-, during and post-dive; *n* = number of divers for which the data was documented; [a]factors listed on the Queensland diver assessment form; [b]cold or overheated combined as a single factor on the Queensland diver assessment form

Possible contributing factor	*n* (%)
Dehydration (*n* = 153)	88 (58)
Seasickness (*n* = 64)	37 (58)
Rough seas (*n* = 61)	32 (53)
Alcohol/Drug use (*n* = 133)	61 (46)
Possible contributing dive factor[a] (*n* = 306)	
Multiple repetitive dives (> 3 / day)	138 (45)
Surface interval < 120 min	136 (44)
Multi-day diving (> 3 consecutive days)	97 (32)
Rapid ascent	95 (31)
Excessive exertion	93 (30)
No safety stop	75 (25)
Reverse profile	72 (24)
Ear problems	67 (22)
Equipment problems	44 (14)
Violated computer/table guidance	35 (11)
Altitude exposure	32 (11)
Buoyancy problems	20 (7)
Thermal stress[b]	16 (5)

non-diving related. Most divers were classified as having mild initial disease grade (*n* = 216, 70%). Paraesthesia was the most common presenting symptom followed by arthralgia/myalgia and poor balance/ataxia (Figure 3). Half of the divers received treatment at the scene (*n* = 155/304), most commonly oxygen (143/155, 92%). Twenty-four divers (*n* = 24/155, 15%) had analgesia, 32 (*n* = 32/155, 21%) had fluids (30 oral, one intravenous and oral, one intravenous only) and two (*n* = 2/155, 1%) had antiemetics at the scene. Time to symptom onset was shorter for divers treated at the scene (*n* = 130) (median 20 min, IQR 00:05, 1:30 h:min) compared to the group of injured divers not treated at the scene (*n* = 139) (median 4 h, IQR 1, 16 h).

RETRIEVAL

One-third of the injured divers (*n* = 104) were primarily retrieved, half by boat (*n* = 52/104). More than three quarters of the injured divers required a secondary retrieval (*n* = 236), half by road. Only 24 injured divers had a tertiary retrieval.

RECOMPRESSION

A total of 285 (93%) of the injured divers received HBOT. Figure 2 depicts, by initial disease grade, the divers that did not receive HBOT. Nineteen of 216 injured divers initially classified as having a mild disease grade were not

Figure 3
Frequency of presenting symptoms of the injured divers who may have exhibited more than one symptom; the 'other' category consists of 26 discrete symptoms. LOC – level of consciousness

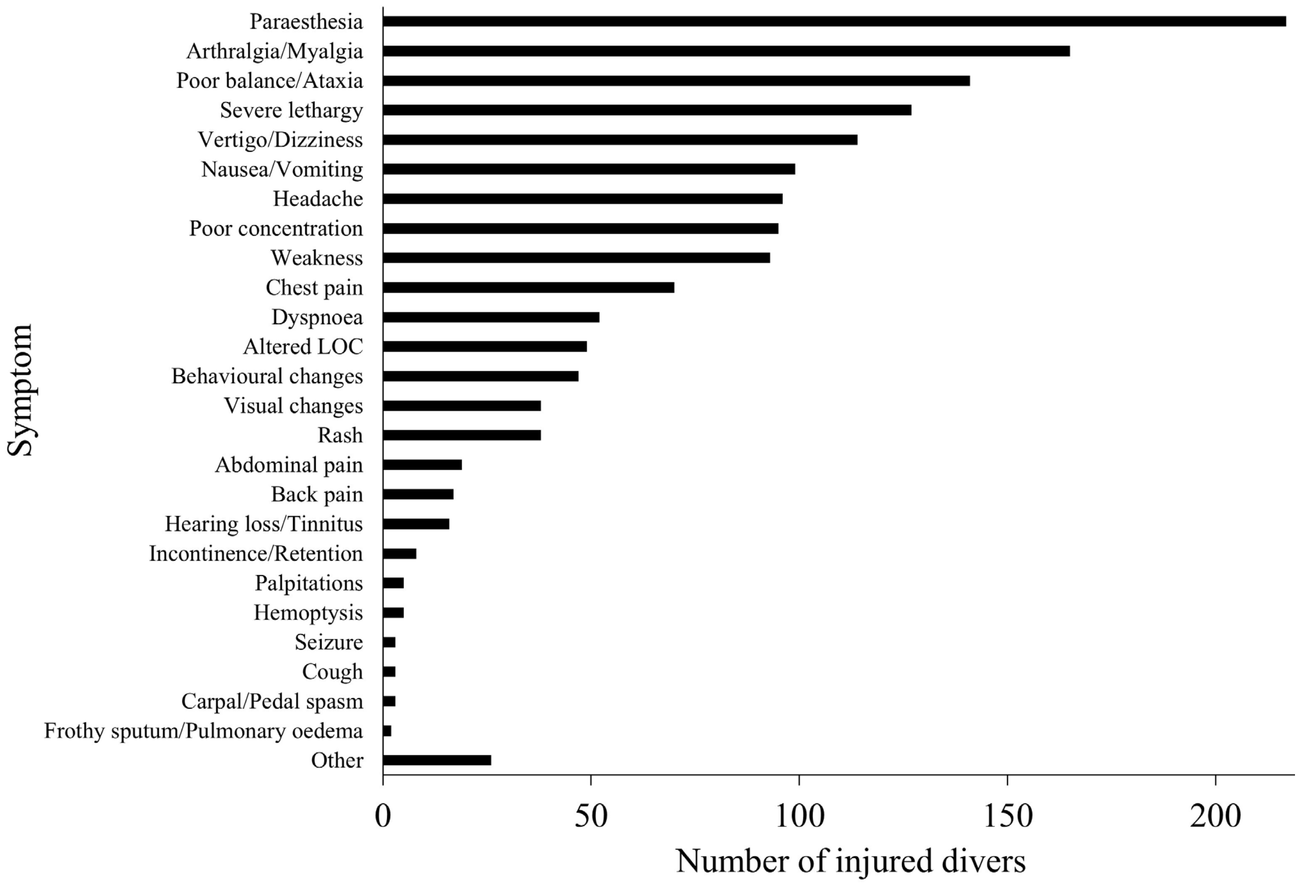


Table 6
Time to hyperbaric oxygen treatment (HBOT) post-symptom onset for all divers and subgroups; **P* = 0.001 vs divers with symptom onset during the dive; IQR – interquartile range

Parameter	Median (IQR) (h:min)
Time to HBOT all injured divers, *n* = 283	38:51 (22:11, 69:15)
Time to HBOT for divers with symptom onset post-dive, *n* = 256	41:30 (22:26, 70:37)*
Time to HBOT for divers with symptom onset during the dive, *n* = 27	23:48 (9:45, 31:06)
Time to HBOT for divers treated at scene, *n* = 145	26:12 (17:20, 49:48)
Time to HBOT for divers primarily retrieved, *n* = 97	21:40 (10:30, 38:10)

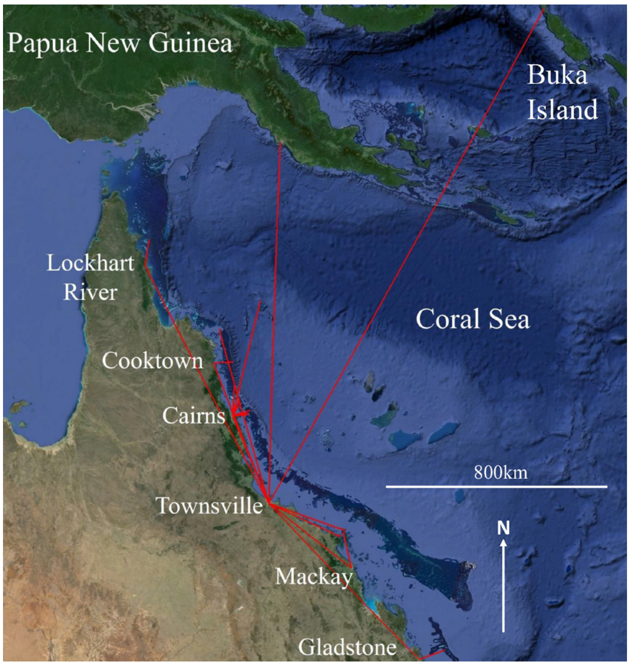
recompressed and for two the time to HBOT could not be calculated. Of these 19 non-recompressed divers, 11 had a non-diving related final diagnosis, seven had a final diagnosis of decompression sickness with one a disease evolution of stable and the other six resolving. One injured diver had a final diagnosis of possible cerebral AGE and saltwater aspiration. Due to a previous medical condition and resolution of symptoms, it was decided not to recompress this diver. All injured divers with initial disease grade of moderate (*n* = 57) were recompressed. Two injured divers classified as having initial severe disease grade (*n* = 33) were not recompressed. The final diagnosis in both cases was immersion pulmonary oedema. Divers with symptom onset during the dive had shorter times to HBOT compared to those with post-dive symptom onset (Table 6). Time to HBOT decreased as initial disease grade severity increased.

Of the 283 divers that underwent HBOT, none had HBOT commenced under three hours and only eight had HBOT commenced under six hours. Only 35 divers (12%) commenced HBOT under 12 hours and only 93 divers (33%) commenced HBOT under 24 hours. Three extreme

Table 7
Reasons for delays to hyperbaric oxygen treatment (HBOT); IQR – interquartile range; NBOT – normobaric oxygen treatment; * retrieval pathways for these cases are shown in Figure 4

Reason for delay	*n* (%)	Median (IQR) time to HBOT (h:min)	Initial disease severity		
			mild	moderate	severe
Delayed presentation for medical review	100 (35)	48:30 (29:58, 91:53)	83	15	2
Extreme retrieval distance (500 to > 1,700 km)	91 (32)	22:03 (11:48, 41:15)	42	27	22*
NBOT overnight then transferred	24 (8)	31:18 (23:11, 45:23)	20	4	0
Kept diving	22 (8)	84:45 (56:36, 244:11)	18	2	2
Initial misdiagnosis	15 (5)	73:32 (49:50, 134:56)	12	2	1
No delay	10 (4)	5:39 (3:32, 6:54)	3	3	4
NBOT with symptom reoccurrence	10 (4)	48:16 (30:08, 78:03)	9	1	0
NBOT overnight with morning HBOT	9 (3)	22:22 (19:34, 24:39)	7	2	0
Refused initial transfer	2 (< 1)	68:03 (24:31)	1	1	0

Figure 4
Retrieval pathways for divers with severe initial disease grade and extreme retrieval distance; $n = 22$



outliers were identified with a time to HBOT of greater than 373 h from symptom onset. All three divers were occupational divers who presented late for initial medical review. Reasons for delay to HBOT are listed in Table 7. Initial misdiagnosis and the lack of knowledge of the need for HBOT led to a delay in the referral and transfer of some divers to Townsville. Extreme retrieval distance was the most common reason for delay to HBOT for divers with severe initial disease severity. Retrieval pathways for these divers ($n = 22$) are shown in Figure 4. Only one of these divers was directly transferred to Townsville with the remaining 21 requiring more than one retrieval leg.

The initial recompression treatment table used was most often a modified Royal Navy (RN) 62 (US Navy treatment table 6), with only a small number of table extensions required (Table 8). Most divers required only a few treatments and had a good outcome (Table 8). Sixteen divers required more than 10 treatments, only one of these had mild initial symptoms (symptoms initially resolved on normobaric oxygen therapy) and only three had complete resolution of symptoms. Seven of these divers had a modified RN 62 as their first follow-up treatment table, four of whom had a Comex 30 as their initial treatment table. The other follow-up treatments were a combination of 180 kPa (100 min with 2 x 5 min air breaks) and 140 kPa (120 min with 2 x 5 min air breaks) treatment tables.

There were statistically significant differences between initial disease grade and time to symptom onset, time to oxygen commencement, and time to HBOT (Table 9). Divers with more severe initial disease grade had a shorter time to symptom onset, oxygen commencement, and HBOT. There was no statistically significant difference for duration of pre-HBOT oxygen therapy between the three initial disease grade groups ($P = 0.408$).

POSSIBLE CONTRIBUTING FACTORS FOR CLINICAL OUTCOMES

The small group of injured divers with major incapacity at the completion of hyperbaric treatment ($n = 2$) had severe initial disease grade, short times to symptom onset post-surfacing (1 min) and to oxygen commencement (5 min), and HBOT (6 h 49 min and 7 h 3 min). Due to small numbers, the clinical outcome groups 'moderate impairment' ($n = 19$) and 'major incapacity' ($n = 2$) were combined into one group for further analysis. There were no statistical differences between the clinical outcome groups for time to symptom onset, time to oxygen commencement or time to HBOT in the group of divers with severe initial disease grade (Table 10). There was

Table 8

Initial hyperbaric treatment table, number of treatments and clinical outcome; IQR – interquartile range; *n* = number of divers for whom the data was documented

Treatment parameter	*n* (%) or median (IQR), range
Initial treatment table (*n* = 285)	
Royal Navy 62	262 (92)
Comex 30	12 (4)
Other	11 (4)
Extensions and treatment numbers	
Table extension (*n* = 283)	30 (11)
Median (IQR) treatments (*n* = 285)	3 (2, 4), range 1−37
Clinical outcome (*n* = 306)	
Well, no residual signs or symptoms	147 (48)
Minor symptoms, no functional significance	138 (45)
Residual symptoms, moderate impairment	19 (6)
Major incapacity	2 (1)
Death	0

Table 9

Comparison of initial disease grade with timelines as specified (median IQR hours:minutes [h:min]); * Kruskal-Wallis test; # does not include injured divers with symptom onset during the dive; [a]significant difference between mild and moderate; [b]significant difference between mild and severe; [c]significant difference between moderate and severe; IQR – interquartile range; HBOT – hyperbaric oxygen treatment

Timeline	Mild	Moderate	Severe	*P*-value*
Time of symptom onset post-dive# (h:min)	2:00 (0:15, 8:00)[a,b] *n* = 199	0:15 (0:02, 2:00)[a] *n* = 51	00:10 (0:01, 1:00)[b] *n* = 19	< 0.001
Time to pre-HBOT oxygen start post-symptom onset (h:min)	9:00 (0:39, 31:57)[a,b] *n* = 169	1:27 (0:15, 11:48)[a] *n* = 54	00:15 (0:06, 3:40)[b] *n* = 31	< 0.001
Time to HBOT (h:min)	46:55 (26:10, 79:15)[a,b] *n* = 195	24:31 (12:10, 43:16)[a,c] *n* = 57	11:28 (7:57, 23:48)[b,c] *n* = 31	< 0.001

Table 10

Comparison of clinical outcome after completion of hyperbaric oxygen treatment (HBOT) with timelines as specified (median IQR hours:minutes [h:min]) for divers with initial severe disease grade; *Kruskal-Wallis test; [a]does not include injured divers with symptom onset during the dive; [b]one extreme outlier excluded due to a non-DCI final diagnosis

Timeline	No residual symptoms	Minor residual symptoms	Moderate / major residual symptoms	*P*-value*
Time to symptom onset post-dive[a] (h:min)	0:01 (< 0:01, 0:20) *n* = 6	0:01 (0:01, 3:00) *n* = 5	00:45 (0:01, 2:00)[b] *n* = 7	0.322
Time to oxygen start post-symptom onset (h:min)	0:10 (0:10, 3:00) *n* = 11	2:22 (0:07, 6:22) *n* = 12	00:11 (0:05, 5:16) *n* = 8	0.462
Time to start HBOT (h:min)	8:08 (6:57, 66:59) *n* = 9	16:53 (8:16, 23:33) *n* = 12	13:42 (7:40, 41:18) *n* = 10	0.347

a statistically significant association between initial disease grade and combined clinical outcome ($P < 0.001$, df 4). *Post hoc* analysis showed that divers with moderate or severe initial disease grades had poorer outcomes.

Discussion

Divers with higher initial disease grade had earlier time to symptom onset, oxygen commencement, shorter time to HBOT and poorer outcomes. These findings appear to be consistent with other studies where initial disease severity is related to outcome, but other contributing factors are difficult to determine.[5,8,9] However, almost all the divers in this study had a substantial delay to HBOT, precluding meaningful evaluation of the effect of time to HBOT on clinical outcome.

Many factors (Table 5) have been proposed as possibly contributing to the risk of DCS and outcomes.[3,10,11] Numerous retrospective reviews[5,8,9,12–14] have reported the incidence of these factors, with one study reporting that 76% of injured divers had one or more contributing factors.[15] Despite ongoing attempts, there appears to be no consistent association between these proposed contributing factors and DCS risk or outcome. The retrospective nature of these studies probably greatly contributes to the difficulty in delineating pertinent risk factors. Incomplete documentation often leads to exclusion of cases[16,17] or possibly missing pertinent negatives in data sets as only positive responses are often recorded. Self-reporting would only include the items a diver believed to be a possible risk factor.[13,18] A prospective study collecting information on possible risk factors would greatly improve our understanding of risk and help focus educational opportunities for divers, dive operators, and dive medical personnel.

The divers in our study were largely young (Table 3), possibly reflecting the Australian backpacker (younger people travelling overseas, often on a working visa, staying in hostels) commonly taking scuba lessons and diving on the GBR. Injured divers are often young[12,14,16,19–21] especially compared to deceased divers. Divers Alert Network (DAN) fatality data from 2018 found a median age of 56 years of age[22] in deceased divers and Queensland data for 2000–2019 found a median age of 48 (IQR 32, 57) years.[2] Older divers are more likely to have medical conditions and poor physical fitness. Previous medical conditions are frequently listed in fatality reviews[2] but infrequently documented in retrospective reviews for divers treated for DCI. Health surveillance of recreational divers has been an issue discussed in the diving medicine fraternity;[23] however, any recommendations would be difficult to enforce. Divers are encouraged to be reviewed by a medical practitioner after a change in health.[23] Despite this recommendation, an online survey completed by DAN found divers with diabetes, cardiovascular, or respiratory disease rarely modified their diving practices or sought specialist advice.[24] Identifying medical or surgical conditions when divers are treated for DCI could provide an opportunity for discussion with a diving physician, potentially decreasing the risk of death in later years.

Many of the injured divers treated in Townsville were from overseas, possibly due to a regional phenomenon reflecting the high load of visitors who often participate in scuba courses to dive on the GBR. The percentage of overseas divers seems to be even higher than described in other tourist areas.[14,20] This is also reflected in the seasonality of presentations with more cases in the Australian summer months when the ocean water is warmer. In the northern hemisphere, higher call volume for advice is also found in the summer months.[22,25] More injured divers presented over the weekend days. This is unsurprising as dive trips are often planned around other commitments as weekend getaways.

The median time to symptom onset of an hour post-dive in our study was similar to that described in previous reports.[17,19] Other studies reported time to symptom onset of: 30 min,[13] 41 min,[16] and 90 min.[12] Divers in our study with a severe initial disease grade had shorter times to symptom onset. This was consistent with other studies focusing on divers with spinal cord DCS, the time to symptom onset from surfacing being considerably shorter: 5 min,[8] 10 min,[5] and 15 min.[9] Longer times to symptom onset have been associated with better outcomes,[5] while severe initial symptoms are associated with poorer recovery.[26] Together, short delays to symptom onset and severe symptoms should lead to prompt initiation of first aid treatment and arrangement for transport to a recompression facility.[3]

The most common presenting symptoms of paraesthesia and arthralgia/myalgia in our study are in keeping with previously published data.[3,16,21] These symptoms may be mild and vague, often making DCS difficult to diagnose by an inexperienced practitioner. The DAN America 'hotline' was established in 1980 to help injured divers by providing advice for both pre-hospital and hospital care.[22] An Australian hotline, called the Diver Emergency Service (DES), started operation in 1983 providing similar advice in the Asia-Pacific region. DAN World assumed responsibility for the Australian hotline in 2019. Phone advice can be obtained from DAN as well as directly from diving physicians around the world assisting with the diagnosis of diving related injuries, and guidance on treatment and disposition. This is a valuable service especially for centres that may not frequently care for injured divers.

The median time to HBOT in our study was considerable. Other studies have reported median times to HBOT of 6 h (Switzerland),[13] 24 h (Turkey),[16] 32.5 h (Poland),[19] and 2 days (New Zealand).[12] Consistent with our study, two studies in France found that divers with severe initial disease had shorter times to HBOT, 3 h[8] and 2 h 44 min.[5] Delay to recompression seems to increase the risk of incomplete recovery, but only in severely injured divers.[5,26] Previous research found an improvement in outcomes when divers with severe disease received HBOT within six hours.[26] A more recent study has found that divers with spinal DCS treated with HBOT within three hours of symptom onset had less sequelae at time of discharge.[5] None of the divers in our study had HBOT starting within three hours and only eight divers had HBOT commenced within six hours. Most divers in our study presented late for HBOT. Delayed HBOT, greater than 48 hours, has still been found to alleviate symptoms,[27,28] therefore delayed presentation should not preclude HBOT.

Many factors contributed to the delay to HBOT in our study (Table 7). Time to HBOT not only varies with initial disease severity but also by geographical location and distribution of hyperbaric facilities.[20,28] The Townsville hyperbaric unit covers a large geographical area with divers often in remote locations requiring long and complex retrievals. Further in-depth analysis of retrieval pathways will provide information on the factors leading to long retrieval times, identifying areas for improvement.

During our study period no formal follow-up occurred. Follow-up of divers with incomplete recovery is infrequently documented in retrospective reviews and often commented on in the limitations.[15,20] One study presented clinical outcome at one month post-injury in divers with spinal cord DCS, but the details of how this was done were not included.[8] Another study contacted divers treated over a two-year period, 1.5 to 3.5 years later.[21] In this study, 13 divers "*had reduced but lingering symptoms at discharge from hospital*".[21] Out of the 30 divers treated over the two-year period, 24 were contacted, one having died in a subsequent diving accident.[21] Six divers had residual symptoms at the time of contact, but interestingly three of these did not report having symptoms upon completion of their HBOT.[21] One diver suffered a concussion in the intervening years and it could not be determined if the reported symptoms were from DCS or the concussion. No other information was provided on possible reasons for recurrence of symptoms in the divers who had been free of symptoms on discharge.[21] In the current era of electronic communication, it would seem easier to contact previously treated divers whether they were local or tourists, though securing responses is likely to remain challenging. Historically, the Townsville HMU sent out follow-up letters to divers requesting information on clinical outcome and recurrence of symptoms during air travel. This information led to the changing of the advice on flying after hyperbaric treatment for DCI, decreasing the time to three weeks post completion of treatment from previous advice to wait for 4–6 weeks. Despite the reduction, this remains a very conservative recommendation. Follow-up letters are no longer sent to divers, and follow-up information was not documented in any of the charts in this review. Follow-up questionnaires could provide valuable data on recovery of divers especially those discharged with residual symptoms. At the time of discharge, divers are presented with a treatment summary and discussion ensues around returning to diving and flying. This would be an ideal time to verify electronic contact details and discuss the sending of a follow-up questionnaire. This would provide continuity of care for the divers and help with organising clinical review if necessary. Active follow-up of all treated patients would improve the knowledge of the incidence of ongoing permanent sequelae and allow for better prognostication and advice to patients on discharge.

RECOMMENDATIONS

Queensland has a state-wide diver injury assessment form (Appendix A [#]). The form contains information on assessing potential diving related injuries and a fillable section to enter information on dive profiles, risk factors, symptoms, physical assessment, and treatment provided. This form was designed to provide guidance for facilities infrequently encountering injured divers, providing a template of pertinent factors to be collected and discussed when referring to the hyperbaric facilities. Recommended changes to this form have been identified from this study. Thermal stress should be divided into cold and overheated and include the phase of dive at which this occurred.[4] There was poor documentation of thermal stress in the current study perhaps indicating a lack of knowledge of the role it may play in DCS risk. Current diving practice would indicate that a 60 min surface interval between dives is now considered standard, therefore, this item should be changed from 120 to 60 min. Lastly, documenting the incident dive location would assist in identifying high risk dive sites and allow for improved analysis of retrieval pathways and time to HBOT.

LIMITATIONS

This study was retrospective and limited by incomplete records and missing data. Missing data may have contributed to the difficulty to detect correlations between initial disease severity, contributing factors, timelines, and clinical outcomes. Time to treatment for divers with symptom onset during the dive may have been longer than reported as arrival at the surface was used as the starting point for timeline calculations. Divers are encouraged to return to the hyperbaric unit for review should symptoms reoccur, however, there was no attempt at follow up of divers after completion of their hyperbaric treatment, therefore final outcome is unknown. It is unknown if any injured divers were treated with normobaric oxygen therapy either on dive boats or at other health care facilities and not transferred to Townsville for treatment. Therefore, the true incidence of DCI in the Townsville catchment area is unknown.

Conclusions

This review describes 15 years of activity at the Townsville hyperbaric medicine unit. Most divers had mild initial disease severity, required few hyperbaric treatments and had a good outcome. Higher initial disease severity accelerated the speed of care obtained and was the only factor associated with poorer outcome. Improved documentation may enhance the ability to understand the impact of contributing factors on clinical outcomes.

[#] Appendix A can be found on the DHM Journal website: https://www.dhmjournal.com/index.php/journals?id=344

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