Original articles

Oxygen treatment and retrieval pathways of divers with diving-related conditions in Townsville, Australia: a 15-year retrospective review

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Keywords
Arterial gas embolism; Decompression sickness; First aid; Oxygen toxicity; Retrieval platform; Scuba diving; Treatment

Abstract
(Blake DF, Crowe M, Lindsay D, Turk R, Mitchell SJ, Pollock NW. Oxygen treatment and retrieval pathways of divers with diving-related conditions in Townsville, Australia: a 15-year retrospective review. Diving and Hyperbaric Medicine. 2025 30 June;55(2):79–90. doi: 10.28920/dhm55.2.79-90. PMID: 40544136.)
Introduction: First aid for injured divers includes oxygen delivery prior to definitive care. Delay to specialist assessment and/or hyperbaric oxygen treatment (HBOT) may be due to dive site remoteness and limited access to facilities. Townsville has the only hyperbaric facility along the Great Barrier Reef. Analysis of oxygen therapy and retrieval pathways of divers treated in Townsville may assist with establishing future education strategies and resource allocation.
Methods: Data were retrospectively collected on divers assessed at the Townsville hyperbaric medicine unit from November 2003 through December 2018. Demographics, dive incident location, oxygen treatment, retrieval platform and pathway, and initial disease grade were reviewed. Data are presented as frequencies and percentages.
Results: A total of 306 cases were included (184 males). Divers typically received oxygen therapy (87%, 267/305 known) prior to specialist review. The non-rebreather mask was the most frequently used (44%, 28/63) followed by in-water recompression (24%, 15/63). While 34% of the divers were retrieved from the scene (*n* = 104), only 11 (11%, 11/104) were retrieved directly to Townsville. Most divers initially classified as severe were retrieved from the scene (82%, 27/33), only two directly to Townsville. Fifteen cases had three retrieval legs (5%, 15/306).
Conclusions: Most injured divers received oxygen first aid and were transported to Townsville for definitive care with a variable number of retrieval stages. Continuing education of retrieval physicians should address knowledge of diving related injuries and highlight cases that may benefit from expedited transfer.

Introduction

The Great Barrier Reef (GBR) is the world's most extensive coral reef ecosystem, extending from the northern tip of Queensland, Australia to just north of Bundaberg. As one of the best-known reef systems in the world, over two million visits are made to the reef each year.[1] Midway along the coastline parallel to the reef system is located the city of Townsville. The Townsville University Hospital houses the only hyperbaric facility along the GBR, providing specialist advice and recompression/hyperbaric oxygen treatment (HBOT) for divers with decompression sickness (DCS) or arterial gas embolism (AGE) (collectively referred to as decompression illness [DCI]) on the GBR and neighbouring Pacific Islands. The next nearest hyperbaric facility is located 1,400 km south of Townsville in Brisbane. For the purpose of this study, the term 'injured divers' refers to those with suspected DCI or another malady after a dive such as immersion pulmonary oedema thought to require review by a diving specialist. A centralised Queensland retrieval service assists with the transport of injured divers to definitive treatment, with the northern zone co-ordination centre located in Townsville. Rotary and fixed wing assets are located along the Queensland coast, including a jet in Townsville for international and long-haul retrievals (Figure 1). Referrals to the coordination centre may come directly from dive boats (skippers), the Queensland Ambulance Service (supervisors), health care facilities (nurses or doctors) or diving physicians (emergency hotlines or hyperbaric facilities). It is the job of the clinical coordinator to provide medical advice and determine the urgency, retrieval platform, and appropriate destination for injured divers.

First aid treatment for divers may include oxygen delivery while obtaining specialist advice and preparing for evacuation.[2] In relevant scenarios, surface oxygen may reduce or resolve symptoms, and hasten recovery,[3] and therefore should be initiated as soon as possible when symptoms develop, and maintained until definitive treatment can be delivered. Many dive sites are remote, requiring a variety of retrieval platforms and stages to be used in transferring injured divers to a facility capable of providing HBOT. Organising transport to a hyperbaric facility can be challenging and early advice from a diving physician can assist in appropriate patient selection, treatment options, level of urgency and destination decisions.

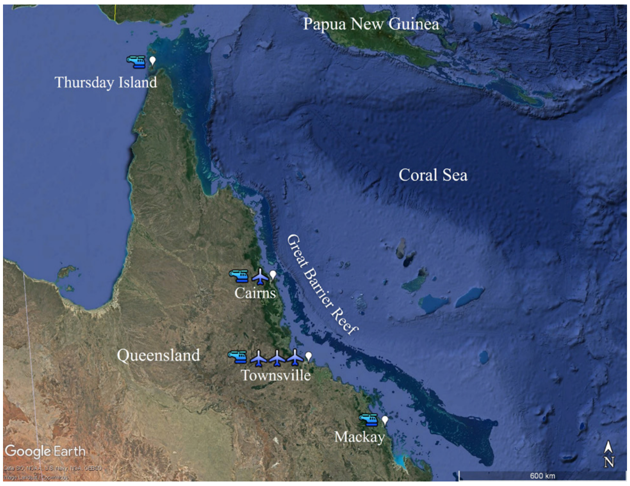
The aim of this retrospective review was to analyse oxygen therapy and the retrieval platform and pathways of injured divers presenting to the Townsville hyperbaric medicine unit. Mapping of the retrieval pathway will provide insight into the appropriateness of aircraft base locations and destination decisions. Analysis of pre-hospital care and retrieval pathways of these injured divers could assist with establishing future education strategies and resource allocation.

Methods

Ethics approval was granted from the Townsville Hospital and Health Service (LNR/2019/QTHS/51229) and James Cook University (H7767). This retrospective review includes all injured divers assessed and treated at the Townsville hyperbaric medicine unit (THMU) after a previous report,[4] from 4 November 2003 through 31 December 2018. Cases were identified for inclusion by reviewing yearly HMU patient logs and electronic discharge summaries.

Retrieval Services Queensland databases (Queensland neonatal emergency transport service, clinical coordination retrieval information system, and Brolga [retrieval information system]) were searched using keywords 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 recorded so that cases could be correlated with THMU data, looking for any missed cases and ensuring no cases were duplicated.

Figure 1
Map of Queensland with northern coastal aeromedical retrieval bases and assets. The vehicle symbol (helicopter or plane) indicates the number of aeromedical assets at each base; Thursday Island to Townsville 1,000 km; Cairns to Townsville 350 km, approximately 60 min rotary flying time; Mackay to Townsville 389 km, approximately 60 min rotary flying time



Individual charts were reviewed, and data extracted to pre-formatted templates. The divers' ages in years and sex were recorded. Time of symptom onset was defined in two ways. Firstly, whether symptom onset occurred underwater during the dive or post-dive after arriving at the surface. Secondly, an actual time duration from arrival at the surface to 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 these cases. Initial disease grade was classified using a previously published scale (Table 1).[4] Treatment details were recorded including time to oxygen commencement post-symptom onset, oxygen delivery method, and change of symptoms with oxygen. Oxygen therapy duration was calculated and documentation of any symptom(s) of oxygen toxicity collected.

Retrieval details were collected including platform (boat, rotary wing, fixed wing, or road), oxygen delivery, retrieval origin and destination, and type of retrieval (primary, secondary, or tertiary). Primary retrievals were classified as retrievals from the scene of the dive incident or other prehospital location.[5] 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 a dive boat returned to shore without any urgency after completing their trip, this was not considered a retrieval. Secondary retrieval was defined as a transfer between health care facilities. This may be a second

Table 1
Initial disease severity grade using the established Townsville Hospital categories;[4] mild and moderate symptoms are invariably decompression sickness (DCS) while arterial gas embolism events would be classified as severe. It is acknowledged that these classifications do not correspond exactly with the final definition of mild DCS arising from the workshop where Reference 4 was presented, but they were historically applied to the Townsville data and so are used here

Severity	Definition
Mild	Symptomatic with no objective signs except: Minor skin rash Lymphatic DCS Sharpened Romberg test < 30 seconds
Moderate	Symptomatic 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

retrieval leg after a primary retrieval or the transfer between two health care facilities after self-presentation. Tertiary retrieval was defined as a third retrieval leg transfer between health care facilities. Road retrievals included ambulance, bus, or car. Assessment by a health care professional and oxygen use prior to review in the THMU were collected. In relevant cases, time to start of HBOT following symptom onset was determined. All treatments were completed in a multi-place rectangular hyperbaric chamber (Fink Engineering Pty Inc., Warana, Queensland, Australia). Clinical outcome at the end of HBOT was classified as no residual symptoms, minor residual symptoms, or moderate/major residual symptoms.[6,7]

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 a pre-formatted Excel (Microsoft Office 365, Redmond, Washington, USA) worksheet.

ANALYSIS

Data are presented using frequencies and percentages for categorical variables, and medians and interquartile range [IQR] for continuous variables as all data were non-normally distributed as assessed using Shapiro-Wilk tests. The Mann-Whitney U test was used for analysis comparing times for oxygen commencement between divers with symptom onset during versus symptom onset after the dive and for oxygen duration in divers with and without symptoms of oxygen toxicity. The Kruskal-Wallis test was used for analysis comparing times for oxygen commencement for divers treated at the scene by initial disease grade. Spearman rank-order correlations were computed to examine the relationship between time to symptom onset and time to oxygen commencement. Pairwise two-tailed z tests were used for *post hoc* analysis with Bonferroni correction. Significance was accepted as $P < 0.05$. The Statistical Package for the Social Sciences version 28.0.0 (SPSS®, IBM® Corporation, Armonk, New York, USA) was used for analysis.

Retrieval data including mode of retrieval, and primary, secondary, or tertiary retrieval destinations were collected. Geospatial mapping of the retrieval pathway was completed by entering latitudes and longitudes or names of dive sites and retrieval destinations into Google Earth Pro (NOAA, 2015). Sites and destination placemarks were visually verified (zooming in) on the map and adjustments made to coordinates to ensure appropriate positioning. Retrieval destination appropriateness for divers with severe initial disease grade and primary retrievals was examined. Retrieval pathways of divers with three retrieval legs were evaluated for appropriateness. Initial disease severity, diagnosis, need for HBOT, and distance from Townsville were used to assess appropriateness of primary destination and staging. Identified cases were reviewed by two diving medicine and retrieval experts with extensive knowledge of the geographic area and capabilities of retrieval assets and facilities. 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.

Results

A total of 310 injured divers were identified during the study period with retrieval pathways as long as 3,200 km. Four divers were excluded as their paper medical records had been destroyed following national medical record guidelines, leaving 306 divers for the analysis. The median age of the divers was 29 [interquartile range 24, 35] years and 60% were male. Most were recreational divers (72%, 187/260) performing no-decompression diving. Other diver demographics and dive incident details for this cohort have been published elsewhere.[7]

Most symptoms started after the incident dive (90%, 275/306). Median time to symptom onset was 60 [10, 360] min in the divers whose symptoms commenced after surfacing and shorter for divers receiving oxygen at the scene (20 [5, 90] min), and for those primarily retrieved (15 [2, 90] min). Time to symptom onset was shorter in divers with severe initial disease grade (details previously published).[7]

Most of the injured divers received oxygen therapy (87%, 267/305) prior to assessment by a diving physician. Of the divers with a final diagnosis of DCI, 89% (245/274) received oxygen therapy. A high percentage of divers treated at the scene were given oxygen (Table 2). Other treatments included analgesia, antiemetics, and fluid administration. There was poor documentation of the type of oxygen delivery system used, but of those with documentation the non-rebreather mask was most often used with demand valve systems being less common. Most divers had partial or full relief of their symptoms with oxygen treatment (Table 2). In cases where the oxygen delivery method and change in symptoms were documented, symptom improvement was seen in 81% (35/43) of divers breathing surface oxygen and in 78% (7/9) divers receiving in-water recompression (IWR) on oxygen. Further evaluation comparing oxygen delivery device and change of symptoms could not be completed due to incomplete data.

The vast majority (14/15) of divers who received IWR were conducting occupational dives. The majority conducted their dives using a surface-supplied breathing system (9/15). Two were using open-circuit scuba and four had no documentation of the breathing system used. All IWR was done using surface-supplied systems (Table 2). Most divers undertaking IWR (9/15) were in remote locations 500 to 1,000 km from Townsville, three were diving 350 km from Townsville, one was diving 200 km from Townsville and two dive sites were unknown.

Of the divers who had symptom onset during the dive, most (71%, 22/31) received oxygen at the scene. Divers with symptom onset during the incident dive had significantly shorter times to oxygen commencement than divers with symptom onset post-dive (Table 3). Those who had severe initial disease grade and received oxygen at the scene had shorter times to oxygen onset than those with mild initial disease grade (Table 3). The Spearman rho showed a significant positive correlation between time of symptom onset and time of oxygen start ($r_s = 0.4$, $n = 225$, $P < 0.001$). Duration of oxygen delivery for the group of injured divers is presented in Table 3. Divers with symptom onset during dives did not have significantly longer oxygen treatment durations than those with symptom onset post-dive ($P = 0.85$). Divers with oxygen treatment started at the scene had significantly longer oxygen duration than those who did not have oxygen started at the scene (Table 3). Only 35% (46/132) of the injured divers received continuous oxygen.

The presence or absence of oxygen toxicity was infrequently documented. Of those cases with documentation ($n = 41$), 88% described oxygen toxicity. Most of the cases were mild pulmonary oxygen toxicity (92%) with only three cases of possible central nervous system (CNS) toxicity (one nausea, one lip tingling, and one metallic taste). Pulmonary oxygen toxicity was documented in seven cases while breathing normobaric oxygen (two during fixed wing retrievals), in 15 cases while during HBOT and in 11 cases the timing was undetermined. The three cases of possible central nervous system oxygen toxicity were all during HBOT. The cases of oxygen toxicity during HBOT were all given air breaks and treatments continued. Pre-HBOT oxygen delivery duration was significantly longer in the oxygen toxicity group (Table 3). Three divers with oxygen toxicity were international retrievals, one had received HBOT on a Pacific Island prior to the transfer to Townsville. The removal of the oxygen mask by the diver was not recognised as oxygen toxicity by the retrieval team and the diver was sedated to enforce the wearing of the mask. Only one diver who had received IWR on oxygen had possible CNS oxygen toxicity (nausea). Of the divers who received continuous oxygen ($n = 46$), six had documented symptoms of pulmonary oxygen toxicity and two had documentation of no symptoms of oxygen toxicity. The median duration of oxygen delivery in the group who had continuous oxygen and symptoms of oxygen toxicity was 7:20 [3:56, 10:29] h:min.

Of the injured divers primarily retrieved, the majority had oxygen delivered during the retrieval (Table 4). Of the divers who had a secondary retrieval, most had oxygen delivered during the aeromedical retrieval (rotary wing = 93%, 14/15, fixed wing = 91%, 84/92 [eight cases missing data]) (Table 5). The rotary wing secondary retrieval where the

Table 2

Pre-hospital treatment of injured divers; [a]treatment included fluids, medications, and oxygen; [b]n = number of divers for which the information was documented; CPR – cardiopulmonary resuscitation; ROSC – return of spontaneous circulation

Parameter	*n* (%)
Treatment[a] at scene $n = 304$[b]	155 (51)
Oxygen at scene $n = 155$[b]	143 (92)
Other (CPR, ROSC then oxygen)	1 (< 1)
Initial disease grade mild $n = 216$[b]	82 (38)
Initial disease grade moderate $n = 57$[b]	37 (65)
Initial disease grade severe $n = 33$[b]	24 (73)
Oxygen delivery method $n = 63$[b]	
Non-rebreather mask	28 (44)
In-water recompression (IWR)	15 (24)
IWR oxygen	12 (19)
IWR air	3 (5)
Demand valve	13 (21)
Bag valve mask	4 (6)
Simple face mask	3 (5)
Change of symptoms with oxygen $n = 124$[b]	
Partial relief	86 (69)
Full relief	15 (12)
No relief	17 (14)
Worse	3 (2)
Relapsing	2 (2)

Table 3

Time to and total duration of oxygen delivery pre-hyperbaric oxygen therapy post incident dive; *P < 0.001 Mann-Whitney U test; †P = 0.006 Mann-Whitney U test; ¥P = 0.017 Kruskal-Wallis test

Parameter	Median [IQR] h:min
Time to oxygen start post-symptom onset, n = 254	4:00 [0:30, 24:27]
Time to oxygen start where symptom onset was post-dive, n = 227	5:00 [0:30, 26:30]*
Time to oxygen start where symptom onset was during dive, n = 27	00:15 [0:10, 2:30]*
Time to oxygen start post-symptom onset where treated at scene, n = 132/143	00:30 [0:10, 2:00]
Mild initial disease grade, n = 74/82	00:30 [0:15, 2:30]¥
Moderate initial disease grade, n = 35/37	00:20 [0:10, 1:58]
Severe initial disease grade, n = 23/24	00:10 [0:05, 00:30]¥
Duration of oxygen delivery, n = 256	10:00 [6:00, 16:14]
Duration of oxygen delivery where symptom onset was during dive n = 27	9:05 [7:30, 12:05]
Duration of oxygen delivery where oxygen was started at scene n = 145	11:25 [6:55, 18:11]*
Duration of oxygen delivery where oxygen was NOT started at scene n = 109	8:00 [4:07, 13:17]*
Duration of oxygen delivery in divers with no oxygen toxicity or no documentation of oxygen toxicity n = 221	9:03 [5:07, 15:35]†
Duration of oxygen delivery in divers with documentation of oxygen toxicity n = 35	14:16 [9:06, 18:05]†

Table 4

Primary retrieval details; QAS – Queensland ambulance service; [a]n = number of divers for which the information was documented; [b]World Health Organization definition

Parameter	n (%)
Primary retrieval, n = 306	104 (34)
Oxygen during primary retrieval n = 81[a]	77 (95)
Primary retrieval initial disease grade n = 104	
Mild	42 (40)
Moderate	35 (34)
Severe	27 (26)
Primary retrieval platform n = 104	
Boat	52 (50)
Rotary wing	26 (25)
Road (QAS = 19, self = 2)	21 (20)
Fixed wing	5 (5)
Primary retrieval destination n = 104	
Cairns	37 (35)
Townsville	11 (10)
Torres Strait and Pacific Is[b]	10 (9)
Lizard Island	9 (9)
Cooktown	8 (8)
Alva Beach/Ayr	7 (7)
Whitsunday islands/Proserpine	7 (7)
Lockhart River	4 (4)
Mossman/Port Douglas	4 (4)
Gladstone	2 (2)
Mackay	1 (1)
Other	4 (4)

Table 5

Secondary retrieval details; QAS-Queensland ambulance service; [a]n = number of divers for which the information was documented; [b]World Health Organization definition

Parameter	n (%)
Secondary retrieval n = 306	236 (77)
Oxygen during secondary retrieval n = 115[a]	111 (97)
Secondary retrieval platform n = 235	
Road (QAS = 20, bus = 38, self = 53)	127 (54)
Fixed wing	92 (39)
Rotary wing	15 (6)
Boat	1 (< 1)
Secondary retrieval destination n = 236	
Townsville	211 (89)
Cairns	19 (4)
Torres strait and Pacific islands[b]	8 (3)
Whitsunday islands/Proserpine	2 (1)
Alva beach/Ayr	1 (< 1)
Mackay	1 (< 1)
Mossman/Port Douglas	1 (< 1)
Other	3 (1)

Table 6
Tertiary retrieval details; [a]n = number of divers for which the information was documented

Parameter	*n* (%)
Tertiary retrieval $n = 306$	24 (8)
Oxygen during tertiary retrieval $n = 20$[a]	18 (90)
Tertiary retrieval platform $n = 24$	
Fixed wing	18 (75)
Rotary wing	4 (17)
Road (bus = 2)	2 (8)
Tertiary retrieval destination $n = 24$	
Townsville	24 (100)

diver did not receive oxygen was completed using an Australian military helicopter. The pattern was similar for tertiary retrievals with 90% of the divers retrieved aeromedically receiving oxygen (Table 6).

Most of the injured divers were assessed by a health care professional prior to arrival at the THMU (95%, 290/306). This included physicians diving on the dive boat, primary retrieval physicians, nurses in primary health care centres, general practitioners, and emergency physicians. Just under half (49%, 151/306) of the injured divers had at least two medical assessments prior to review by a hyperbaric physician, 14% (42/306) had three medical assessments and 2% (7/306) had four medical assessments. A high percentage of the divers received oxygen at these visits (78% [199/256], 86% [123/143], 80% [32/40] and 50% [3/6] respectively).

The most common primary retrieval destination was Cairns (Figure 1), and the most common retrieval platform was a boat (Table 4). The 'other' destination category consisted of different ports along the Queensland coast (Magnetic Island, Bowen and Gympie) as well as an international site (Indonesia) (Table 4). More than three-quarters of the injured divers required a secondary retrieval. Road transfer was the most common modality with Townsville the most frequent destination (Table 5). The 'other' destination category included Brisbane, Magnetic Island, and Julia Creek (Table 5). Only 24 injured divers had a tertiary retrieval, all to Townsville (Table 6).

The majority of the injured divers initially classified as severe (82%, 27/33) were retrieved from the scene (Table 4). The six divers not retrieved from the scene had a variety of reasons for not being primarily retrieved. Two had symptom onset during flights post diving, one went back to their accommodation and symptoms worsened, one presented to a general practitioner after returning from the dive trip, one self-transported to a hospital in Papua New Guinea, and for one diver there were two doctors on the dive boat who provided care while the boat steamed back to shore. Eighteen (18/27) of these severe cases were within a radius where they could have been primarily retrieved directly to Townsville. Only two were retrieved directly to

Figure 2
Retrieval pathways, assets, and destinations of injured divers with severe initial disease grade in the Cairns area. The vehicle symbol describes the asset used (helicopter, boat, ambulance, or plane), and the number of symbols represents the number of divers transported using that asset

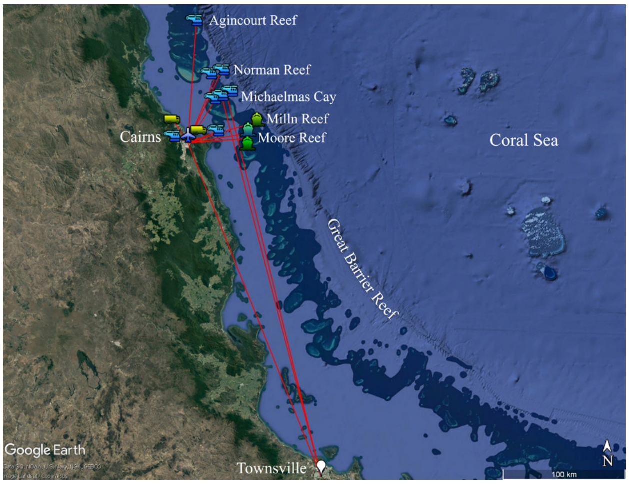


Figure 3
Retrieval pathways, assets, and destinations of injured divers with severe initial disease grade in the Townsville area. The vehicle symbol describes the asset used (helicopter, boat, or ambulance), and the number of symbols represents the number of divers transported using that asset

Townsville (Figure 2). Three went to Ayr hospital (nearest facility) initially and then were transferred to Townsville (Figure 3). Three in the Whitsunday area went by boat to a nearby island, one was then transferred to Mackay hospital (nearest facility) and then onto Townsville, and two were transferred directly to Townville (Figure 4). Ten cases were primarily retrieved to Cairns and then transferred to Townsville, eight by fixed wing and two by rotary wing (Figure 2). Of these 18 severe cases, 14 had a final diagnosis of cerebral AGE, three immersion pulmonary oedema, and one central neurological DCS.

There were 11 primary retrievals direct to Townsville (Figure 5), three were international retrievals direct from

Figure 4

Retrieval pathways, assets, and destinations of injured divers with severe initial disease grade in the Whitsunday area. The vehicle symbol describes the asset used (helicopter, boat, or plane), and the number of symbols represents the number of divers transported using that asset

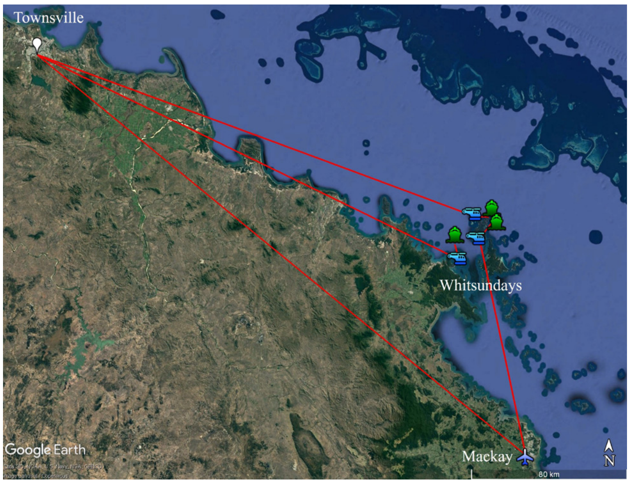
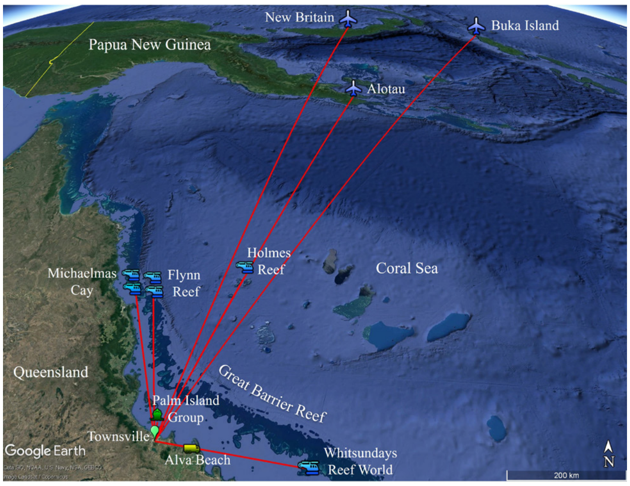


Figure 5

Retrieval pathways and assets of injured divers primarily retrieved to Townsville. The vehicle symbol describes the asset used (helicopter, boat, ambulance, or plane), and the number of symbols represents the number of divers transported using that asset



Papua New Guinea. The other local cases included seven divers with severe neurological symptoms and one diver with severe respiratory distress. Three of the divers did not receive HBOT. Their final diagnoses were cerebrovascular accident, migraine, and immersion pulmonary oedema. Three divers had a final diagnosis of cerebral AGE, one peripheral neurological DCS, and one vestibular DCS. Of the 93 additional primary retrievals, four of the divers had moderate to severe initial disease grades, were transported during daylight, and were within a radius where they could have been transferred directly to Townsville. All the other cases required an initial destination other than Townsville due to severity or distance, needing staging, stabilisation, or treatment at the closest medical facility. Time to start of HBOT was shorter for divers that were primarily retrieved (Table 7).

There were 15 cases with three retrieval legs (Figure 6). Four cases were international retrievals. Two of these cases were treated on a Pacific Island and then transferred to Townsville for further treatment. The 11 Australian cases were retrieved from the dive site by boat, then onward travel for medical review and then onto Townsville for HBOT. Six of these 11 cases were identified as inappropriately staged during the retrieval process. Three of these cases were cerebral AGE, one spinal DCS and two divers were doing decompression diving and had moderate symptoms of DCS.

Most divers had a good clinical outcome and no treated diver died.[7] A higher percentage of divers with moderate (98%, 56/57) or severe (97%, 32/33) initial disease grade received oxygen therapy prior to HBOT than those with mild initial disease grade (83%, 179/216). Divers with moderate or severe initial disease more often had oxygen treatment commenced at the scene of the incident (Table 2). All divers with severe initial disease were retrieved ($n = 33$) and more frequently primarily retrieved (82%, 27/33) than those with mild (19%, 42/216) or moderate (61%, 35/57) initial disease (Table 4).

Discussion

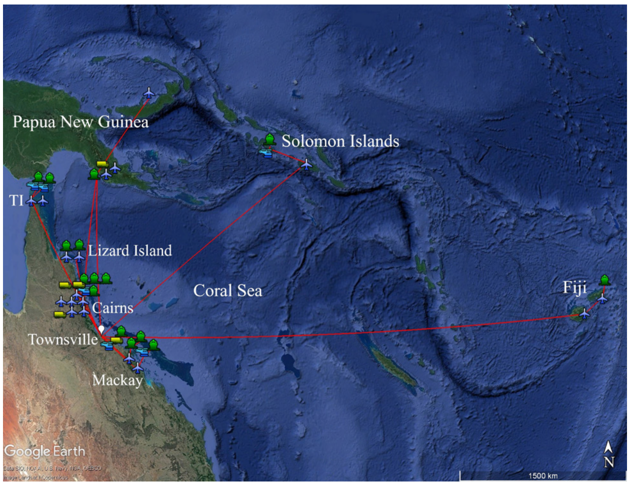
Townsville is strategically located on the east coast of Queensland, providing hyperbaric services to divers on the GBR and neighbouring Pacific Islands. Covering such a large area, there is often a necessity to transport injured divers a great distance to receive HBOT. Most divers in this study received oxygen treatment while awaiting transport and were appropriately staged or primarily transported to Townsville for definitive care.

A large percentage of the injured divers treated in Townsville received oxygen either at the scene, during transport, or at a health care professional visit. Oxygen delivery has long been recommended as a first aid measure for injured divers.[8] Divers Alert Network (DAN) created an oxygen first aid training program in 1991 focusing on the delivery of oxygen in the event of a diving emergency.[9] This program was modified to meet Australian guidelines and introduced in Australia in 1994.[10] Unfortunately, data from calls to DAN Asia-Pacific in 2018 showed only 24% of injured divers received oxygen first aid.[11] This low level of oxygen administration reported by DAN is consistent with other published international studies,[12–17] but unexpected since our incidence of oxygen treatment in North Queensland was much higher. The higher incidence of oxygen delivery in our study may be due to Queensland workplace health and safety code of practice for oxygen use in recreational diving originally published in 1992 (Workplace health and safety Queensland, personal communication, 2023) requiring diving first aid qualifications for all dive masters and instructors and the availability of oxygen at all dive sites.

Table 7
Time to hyperbaric oxygen therapy (HBOT) from time of symptom onset

Parameter	Median [IQR] h:min
Time to HBOT for all injured divers *n* = 283	38:51 [22:11, 69:15]
Time to HBOT for all divers primarily retrieved *n* = 97	21:40 [10:30, 38:10]
Time to HBOT for divers NOT primarily retrieved to Townsville *n* = 89	21:11 [10:43, 35:24]
Time to HBOT for divers primarily retrieved to Townsville *n* = 8	27:05 [5:43, 48:45]

Figure 6
Retrieval pathways and assets of injured divers having three retrieval legs. The vehicle symbol describes the asset used (helicopter, boat, ambulance, or plane), and the number of symbols represents the number of divers transported using that asset; TI – Thursday Island



Although the incidence of oxygen treatment in our study was high, documentation of oxygen delivery device and flow rate was often missing. This appears to be consistent with other studies. One study examining the self-treatment of technical divers experiencing mild symptoms of DCI found a high percentage of divers hydrated orally (74%) and rested (70%) but only a small percentage breathed oxygen (21%) with no documentation of the delivery device used.[18] One paper stated that no divers received oxygen prior to HBOT[19] and one did not mention oxygen in their description of pre-hospital treatment, though they commented on fluids and acetylsalicylic acid administration.[20] One study stated that oxygen was "*routinely administered*"[21] and two others that oxygen was administered during transport[22,23] but details on delivery device and flow rate was not provided.[22] One small study only mentioned in the limitations that most divers received oxygen, stating that there were no data available on the inspired fraction or duration of therapy.[24] In fact, only one of these studies commented on the type of oxygen delivery device used.[23] The current recommendation is to provide the highest possible concentration of oxygen.[2,8] Similar to previous reports,[3,23] the non-rebreather mask was the most frequently used device in our cohort although the oxygen flow rate was infrequently documented. To provide a high level of oxygen to the tissues, a non-rebreather mask may require a flow rate of 15 L·min^{-1}.[25] However, a high flow rate will compromise the duration of available oxygen which is of relevance when treatment occurs at remote dive sites.

After the non-rebreather mask, IWR (breathing air or oxygen) was the second most frequently documented form of oxygen treatment at the scene. IWR breathing oxygen is an established, albeit not universally accepted, strategy for treating DCI,[26] especially at remote dive sites when access to a recompression chamber is not readily available.[27] This procedure is not without risks and requires special equipment and training, with a clear protocol in place prior to use.[28] Indeed, all the divers in our study who performed IWR used surface-supplied breathing systems and all but one had been performing occupational dives. The use of a surface-supplied breathing system suggests that the expertise, equipment, and processes were in place to perform IWR, however, some of the IWR procedures were conducted using air which is not recommended.[27] Despite this, the indication for performing IWR or the protocol used was not documented in the medical chart. Most of the dives were conducted in remote areas but four were conducted in areas reasonably close to Townsville (< 400 km). Given the limited details recorded, further comment on the use of IWR in these cases cannot be made.

Our cohort of injured divers received oxygen for a considerably longer time than previously reported data,[3] but the administration was not necessarily continuous. Oxygen delivery duration is often not stipulated in recommendations.[2] When reported, the recommended durations are often vaguely written and vary from several hours,[29] even if relief of symptoms, to until arrival at a recompression facility.[30,31] Other recommendations include giving oxygen for four to five hours without breaks depending on the time to the chamber,[32] or giving five min air breaks every 30 min if time to recompression is likely to be greater than four hours.[33] A more concrete recommendation is the administration of as close to 100% oxygen as possible for 12 hours with 15 min breaks every four hours.[34] This recommendation is based on the risk of pulmonary oxygen toxicity as an estimate of the maximum amount of time oxygen can be safely breathed rather than the dose of oxygen an injured diver requires.

Oxygen toxicity is a risk for injured divers breathing oxygen. Though poorly documented, 36 divers in our study appeared to demonstrate some level of oxygen toxicity, all but three being pulmonary toxicity, and all with long exposures. Divers with oxygen toxicity had a median oxygen duration (Table 3) greater than the recommended 12 hours.[34,35] Only a small number of the divers in this work received continuous oxygen delivery, with the majority suffering from oxygen toxicity not having had continuous oxygen. Pulmonary oxygen toxicity is a concern from a patient comfort perspective, reversible in its early stages and extremely unlikely to cause harm in this group of patients. If symptoms of pulmonary oxygen toxicity occur, discussing the benefits and risks of ongoing oxygen therapy with an experienced diving physician is warranted. Future guidelines on pre-hospital management of DCI should provide recommendations on the duration of oxygen delivery and address the possible occurrence of pulmonary oxygen toxicity especially during long retrievals or onward transfer after receiving HBOT at another facility.

Air breaks in oxygen breathing during treatment at the scene or during retrievals were for logistical reasons rather than for scheduled air breaks or limited oxygen supplies. Air breaks (15 min off oxygen every four hours) are commonly recommended for injured divers receiving oxygen overnight awaiting HBOT, though this was infrequently documented. Air breaks have been recommended for divers receiving oxygen for longer than 12 hours.[34] This recommendation is thought to reduce the risk of pulmonary oxygen toxicity as well as giving the diver a break from wearing a mask, allowing them to eat and drink. It is interesting that the research supporting the recommendation of only providing oxygen for 12 hours also showed that a 15 min air break every four hours did not decrease the risk of pulmonary oxygen toxicity even though it did decrease its severity.[35] In our experience of long evacuations, clinically significant pulmonary oxygen toxicity seems extremely rare and it is not clear whether potential compromise of DCI treatment by imposing air breaks is justified, or at what time point in a long evacuation this should occur. Further research would be necessary to establish answers to these questions which seem relevant to only a small minority of cases.

Aeromedical assets are frequently used to transfer injured divers as dive sites can be remote and hyperbaric centres few and far between.[20] In our study, rotary wing assets were more often used for the primary versus other retrieval legs and for at least one retrieval leg in 55% (18/33) of divers classified as having severe initial disease. Other studies reported 16%[36] and 39%[6] of divers retrieved by helicopter. Comparable with our results, asset choice can be for geographical considerations[14] or for severity.[6] Helicopters often provide the most timely and efficient means of transfer[14] and may be chosen independent of illness severity.[37] Routes chosen for helicopter retrievals were at the lowest altitude possible. It has been suggested that the vibration generated from rotary aircraft may worsen symptoms of DCS, but there is no published research to support this premise.[38] Even though in our study rotary wing assets were more often used for the primary retrieval leg than for other retrieval legs, due to the location of the dive sites, boat retrieval predominated as the choice for primary retrieval platform.

Logistic difficulties often result in a variety of assets being tasked to transport injured divers to definitive care.[14,39] Previous examination of divers with mild or moderate DCI treated at our facility found that divers transported by surface transport, without oxygen or fluids, had a similar outcome following HBOT to those retrieved using an aeromedical asset.[4] Road retrieval predominated for the secondary retrieval leg in the current study, as it has been the continued practice to have divers with mild symptoms travel to Townsville either by bus or private vehicle. This leaves aeromedical assets available for the transfer of acutely injured patients. Most of these divers had been assessed by a healthcare practitioner (n = 88/91, 97%) and discussed with the hyperbaric medicine physician on-call prior to the decision of suitability for road transfer.

The THMU provides care and support to injured divers along the Queensland coast from Rockhampton north to the Torres Strait Islands as well for some Pacific Islands. Providing coverage for this large area often leads to the need for staging of injured divers at various sites during their retrieval to Townsville. Retrieval destination and asset choice are determined at the time of referral based on the diver's clinical condition, location, asset and staff availability, time of day, weather conditions, and competing tasks. Perhaps not surprisingly, some of our divers required three retrieval legs using different assets. The majority of the current cases that required three retrieval legs were due to these geographical constraints. However, four divers likely should have come to Townsville on their second retrieval leg and two remained at their secondary destination overnight and likely should have been transferred earlier. Similar studies described one asset per retrieval[6,14,36] or only focused on one type of retrieval asset.[23]

Despite the multiple factors playing a role in retrieval decisions, few cases were identified as being inappropriately transported. Of the severe cases, one diver with immersion pulmonary oedema did not require further transfer to Townsville, and one diver with a final diagnosis of cerebral AGE should have primarily gone to Townsville. Four primarily retrieved cases were identified that could have been directly retrieved to Townsville. As described above, six cases with three retrieval legs were inappropriately staged. Decisions on the timeliness of retrieval to Townsville for assessment and possible HBOT is often jointly made by the hyperbaric physician and the clinical coordinator. Documentation of this decision-making process could allow for future analysis and the development of a clinical decision support tool for determining the urgency of the retrieval and the appropriate destination.[37]

LIMITATIONS

This study was retrospective and limited by incomplete records and missing data. Poor documentation of type of oxygen mask used, gas flow rates, starting and stopping times, air breaks, and change in symptoms limited the ability to assess the efficacy of these devices. Documentation of the referral to the THMU and the decision-making process about the retrieval was poor. There was no documentation on tasking deliberations or resource availability. With this decision-making information unavailable, determination of the appropriateness of destination and retrieval timeliness was decided based on the available medical and retrieval notes.

RECOMMENDATIONS

Improved documentation by all persons involved in the care of injured divers, from those providing first aid to diving physicians, in the area of oxygen therapy would allow for a more comprehensive assessment of the effectiveness of the treatment, problems with delivery, and side effects. A prospective study would improve acquisition of this data. Information to be collected could include: type of oxygen delivery system used, gas flow rate, time oxygen started and stopped, IWR protocols used, reasons for stopping, air breaks, change in symptoms of DCI, or any symptoms of oxygen toxicity. Oxygen therapy data should be collected for the whole patient journey, starting from on scene care through completion of treatment.

Despite this need for further research, pre-hospital care and transport of injured divers is well coordinated in Queensland. However, it is important for first responders to obtain early expert advice from an experienced diving physician to assist with decisions regarding on site treatment, retrieval urgency and platform selection as well as appropriate destination. Not all injured divers require recompression, such as divers with immersion pulmonary oedema or divers with mild DCS as recently defined,[28] and can be managed at local facilities with advice from diving experts. Early consultation with experts in the field will ensure that injured divers receive timely treatment at the most appropriate facility reserving aeromedical assets for those needing urgent transport.

Conclusions

A high proportion of injured divers received oxygen treatment while awaiting transport and were appropriately staged or primarily transported to Townsville for definitive care. In-water recompression was used in several cases of occupational diving. Pulmonary oxygen toxicity is a concern when providing extended multi-hour durations of oxygen therapy. The use of many different retrieval assets and legs may be necessary when dive sites are remote and distances to a hyperbaric facility are vast. Continuing education for retrieval physicians should address knowledge of diving related injuries and highlight cases that may benefit from expedited transfer. Improved documentation by all carers of injured divers may enhance the ability to understand the impact of oxygen therapy on divers' outcomes.

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Acknowledgements

Professor Peter A Leggat contributed substantially to the design of this study but died before the manuscript preparation. Alejandro 'Uso' Usobiaga Fabian for assistance with the geospatial mapping. Maps generated by Google Earth Pro, Maxar Technologies. Retrieval Services Queensland for providing data and access to medical records. Dr Clinton R Gibbs for reviewing cases for appropriateness of primary destination and staging. This project is part of a larger group of research studies for a doctoral thesis: "*Pre-hospital treatment of injured divers: oxygen delivery and retrieval considerations*."

Conflicts of interest and funding

This study was funded by a grant from the Australasian Diving Safety Foundation (ADSF). Professors Mitchell and Pollock are members of the editorial board of *Diving and Hyperbaric Medicine* but were not involved in the peer review or publication decision-making process for this article.

Submitted: 15 January 2025
Accepted after revision: 28 February 2025