Decompression illness and other injuries in a recreational dive charter operation

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Abstract
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Introduction: Health and safety within the recreational diving industry are poorly described. We aimed to obtain the true prevalence of decompression illness (DCI) and other diving and non-diving injuries, including occupational injuries, in a large recreational diving charter operation.
Methods: A New Zealand recreational diving operator keeps detailed records of diving activity and event/incident reports. We extracted passenger and crew numbers, dive numbers and incident statistics from all boat trips and associated work-related injuries between 01 January 2008 and 31 December 2014. The records of divers referred to the regional hyperbaric unit for suspected DCI were reviewed retrospectively. Using these data the prevalence of DCI and non-diving injuries were calculated.
Results: There were 65,536 person-trips to sea and 57,072 divers undertook 97,144 dives. Fifty-five injury events were documented over seven years, 31 in customers and 24 in staff. Four divers (including one staff member) diagnosed with DCI underwent recompression therapy, giving a prevalence of 0.41 cases requiring recompression per 10,000 dives, or one case per 24,386 dives, whilst five other divers were assessed as not having DCI. There was one cardiac-related fatality. Thirty-five non-diving injuries (mainly lacerations and minor musculoskeletal injuries) were documented in 30 people resulting in 10 consulting a general practitioner and seven presenting to the local regional hospital emergency department.
Conclusions: DCI requiring recompression was relatively rare in this supervised recreational diving operation. Minor non-diving injuries were the most common adverse event. Compared to other adventure sports, the prevalence of injury in recreational scuba diving is low.

Introduction

There are few reliable estimates of the prevalence of decompression illness (DCI) and little attention has been given to other mishaps or incidents that may occur in a typical recreational diving operation. There are a number of explanations for this, but chief among them is the difficulty in simultaneously acquiring an accurate numerator (number of incidents) that can be confidently matched to an accurate denominator (number of participants or dives). Studies reporting prospectively acquired numerators and denominators pertaining to dive injuries seem rare, particularly in datasets large enough to allow calculation of injury prevalence.

One exception in our jurisdiction is maintained by Dive! Tutukaka (D!T); a recreational dive charter operator that primarily runs day-boat trips from Tutukaka (Northland, New Zealand) to the Poor Knights Islands which lie 20 km offshore. This site is an internationally renowned temperate water diving destination (water temperatures range from 14–17°C during winter to 18–25°C during summer). Access to the islands, which are a National Park, is strictly limited to authorised personnel and informal landings are prohibited. The surrounding waters are a 'no-take' Marine Park. Recreational diving activities are conducted by a number of commercial diving companies and many private boats visit the islands. D!T is the busiest recreational diving operator in New Zealand. Diving injuries sustained during its commercial activities have been reported briefly previously.[1] In the present study, a broader spectrum of health and safety issues within the company, including injuries sustained by employees in the course of their duties, is examined.

Methods

This study was approved by the University of Auckland Human Participation Ethics Committee (Reference number

013608). D!T is required by law to maintain detailed records of customer numbers, dive numbers, staff deployment to sea and any incidents. Much of this is achieved through skipper's vessel reports for each period at sea which include records of dive operations and any injury incidents (diving and non-diving) during each day. Every diver is logged in and out of the water by a Dive Master on board the vessel and maximum depth and total dive time are recorded for every dive, as are any incidents during the dive.

For the period 01 January 2008 to 31 December 2014, data were extracted from two Excel-format databases kept by the company:
1. Diver, snorkeller and non-diving passenger and crew numbers, and dive numbers to provide denominators for calculation of the prevalence of injuries;
2. All individual injury or incident reports pertaining both to diving and non-diving-related events involving both customers and staff, to provide numerators for calculation of injury prevalence.

Dive-related incidents/injuries were those occurring during diving (such as barotrauma) or as a direct consequence of diving but manifesting after surfacing (which includes DCI). Non-diving-related incidents/injuries were other events (such as lacerations and musculoskeletal injuries) occurring at any point in the trip or working day (including those shore-based processes of preparing for and arriving back from each trip).

Each individual incident was de-identified and given a case ID number. The month and year were recorded, whilst the only demographic data were the gender and age of the victim. The incident and any resulting injury/injuries were classified as either diving-related or non-diving-related. The specific injuries sustained were recorded as was the nature of any treatment required by the patient. Any free-text description was extracted from the vessel log or company incident report. If the incident was diving-related, then the maximum depths and total times for that person's dive were taken from the Dive Master's dive log for that diving day. Case records of divers referred to the Slark Hyperbaric Unit in Auckland for suspected DCI were reviewed for the nature and number of recompression treatments provided, and the clinical outcomes were noted.

The primary outcome of the study was the prevalence of DCI calculated both as the number of DCI cases per 10,000 dives and as the number of dives per case of DCI. A principal secondary outcome was calculation of the number of non-diving events resulting in injury per 10,000 trip participants (a combined total of customers and staff).

Results

The diving database contained records of 65,536 person-trips (passengers and crew) to the Poor Knights Islands (or to two wreck sites along the adjacent Tutukaka Coast). There were 97,144 scuba dives undertaken by 57,072 divers. Although not formally recorded, the vast bulk of the diving was on open-circuit (OC) scuba air with a small number of OC nitrox provided by a limited number of customers for their own use. D!T did not provide nitrox diving at that time. There would have been only a small handful of mixed-gas OC and rebreather divers.

Fifty-five injury incidents were documented in the injury database over the study period, 31 in customers and 24 in D!T staff. Twenty were diving-related, nine being suspected DCI, and 35 non-diving related. One diver died after surfacing.

All the nine cases of suspected DCI occurred in OC air divers. Four cases of DCI underwent recompression therapy (Table 1) giving a prevalence of 0.41 cases requiring recompression per 10,000 dives, or one case per 24,386 dives. The other five divers were referred for medical evaluation with symptoms thought possibly caused by DCI (Table 1) but did not undergo recompression because their symptoms were attributed to alternative diagnoses.

There were 11 non-DCI diving-related incidents recorded. Apart from the fatality, these included four barotraumas (two middle ear, one inner ear, one sinus); three panic attacks causing termination of the dive; one uncontrolled inverted ascent (caused by accumulation of air in dry-suit legs); one jellyfish sting and one event in which an unfit diver became short of breath and had to terminate the dive.

The fatality involved a 55-year-old diver who was a foreign tourist travelling with a group. He had a history of two myocardial infarctions, coronary stents, was on cardiovascular medication and wore a Medic Alert bracelet, none of which were declared on his waiver form or to the Dive Master of the day. He was obese, requiring an XXL-sized wetsuit. He was a certified diver who claimed to have done over 50 dives (though only about 25 could be verified). He dived with his own buddy but they separated during the dive as the victim signalled he was low on air 20 minutes into the dive. He was seen by his buddy to surface in no apparent distress and start swimming towards the boat but soon after reaching the boat the victim became unconscious. Basic life support was instituted without success. His computer showed that he had reached a maximum depth of 35 metres' sea water and his air cylinder was empty. The cause of death was given by the Coroner as "*a cardiac event while diving*".

There were 35 non-diving related injuries in 30 people, being 17 lacerations; 12 non-fracture musculoskeletal injuries; three fractures; two electrocutions (both in D!T staff) and one traumatic eye injury. Seventeen of these occurred in D!T staff (who were far outnumbered by passengers). As a result of these injuries, 10 people were known to consult a general practitioner, and seven presented to the local hospital

Table 1
Profiles (depth(s) and total dive time(s)), principal symptoms, recompression treatment and outcome for four cases of decompression illness (DCI) and principal symptoms for five divers referred for evaluation but not recompressed; msw – metres' seawater; USN – US Navy; RNZN1A is a 4 atm abs (405 kPa) heliox treatment table

DCI confirmed, recompressed				
	Dive profiles	**Symptoms and signs**	**Treatment**	**Outcome**
Case 1	23 msw / 52 min + 22 msw / 53 min	Rash + headache	USN Table 6	Full recovery
Case 2	9 msw / 37 min + 10 msw / 37 min	Paraesthesias + joint pain	USN Table 6	Full recovery
Case 3	21 msw / 30 min	Numbness / paraesthesias one side face and body	USN Table 6	Full recovery
Case 4	20 msw / 55 min + 19 msw / 55 min	Rash, shoulder & back pain	RNZN1A + 2 follow up recompressions	Full recovery
Not DCI, not recompressed				
Case 5		Severe fatigue		
Case 6		Chest tightness		
Case 7		Nausea and paraesthesiae		
Case 8		Panic attack, paraesthesiae, cramps, hyperventilation		
Case 9		Fatigue, vertigo		

emergency department. These 35 events in 65,536 person-trips represents a prevalence of 5.3 per 10,000 person-trips, or one event per 1,872 person-trips.

Discussion

The prevalence of DCI in recreational scuba diving reported here represents one of very few estimates based on numerator and denominator data collected prospectively in the field. The same D!T database was previously interrogated for a three-year period between 2005 and 2008 (and data from that evaluation overlap the present data by six months).[1] This revealed seven DCI cases in 70,600 dives (a prevalence of one case per 10,000 dives). Another study which also obtained numerator and denominator data from a database prospectively maintained by a single dive operation reported a strikingly similar prevalence of approximately one case per 10,000 dives.[2] A third study reported data prospectively collected as part of the Divers Alert Network Project Dive Exploration initative,[3] giving a prevalence of 3.11 cases per 10,000 dives.

Other approaches have used less precise measures of the denominator. In one study, regional treated DCI cases provided a numerator, and scuba tank fill numbers over the corresponding region and period served as a denominator.[4] This revealed a notional DCI rate of one case per 10,000 dives (where one tank fill is assumed to equal one dive). Although subject to a number of potential selection, recall and reporting biases another strategy is to use voluntary diver surveys. One such Japanese study estimated a rate of 0.53 cases per 10,000 dives.[5] A survey of Divers Alert Network members reported a similar DCI prevalence of 0.63 per 10,000 dives,[6] and a small survey of mainly experienced divers at several diving symposia reported a rate of 1.83 cases per 10,000 dives.[7] Other studies have derived denominators from various sources with increasing reliance on estimations and assumptions.[8,9] The key elements of the above studies are summarised in Table 2.

It is difficult to reliably interpret any differences in the DCI rates reported between these studies. For example, in the present study we report a rate that is lower than that arising from our earlier analysis,[1] and lower than the rate calculated using similar methodology from another discrete dive operation.[2] It is tempting to conclude that this represents a true improvement or difference in diving safety. D!T is a conservative organisation whose trips are closely supervised

Table 2
Key elements of studies that calculate a prevalence of decompression illness (DCI) in large cohorts of recreational divers

Study	Numerator descriptor	Denominator descriptor	Numerator (DCI cases)	Denominator (dives)	Prevalence (DCI cases per 10,000 dives)
Present study	Prospective field data	Prospective field data	4	97,144	0.41
Davis[1]	Prospective field data	Prospective field data	7	70,600	0.99
Gilliam[2]	Prospective field data	Prospective field data	7	77,680	0.90
Buzzacott[3]	Prospective field data	Prospective field data	38	122,129	3.11
Ladd[4]	Regional clinical data	Regional tank fills	14	146,291	0.96
Nakayama[5]	Retrospective self-report	Retrospective self-report	60	1,140,653	0.53
Ranapurwala[6]	Retrospective self-report	Retrospective self-report	11	174,912	0.63
Klingmann[7]	Retrospective self-report	Retrospective self-report	52	284,067	1.83
Lippmann[8]	Regional clinical data	Informed estimate	188	1,750,000	1.07
Harris[9]	Regional clinical data	Informed estimate	16	57,000	2.81

and incorporate thorough briefings, guided dives and matching of dive sites to diver capabilities. There is evidence from a database of similarly disciplined American scientific dives that attention to safety results in a low prevalence of DCI (33 DCI cases in 1,019,159 dives; approximately 0.3 cases per 10,000 dives).[10]

Both scientific diving in the USA[10] and diving at D!T in NZ are regulated by a wide range of legislation and codes of practice in their respective countries. Whilst the legislative environment in NZ for adventure sports was complex and not well policed during the study period, all employed divers at D!T were required to practice under Department of Labour Health and Safety regulations (ASNZS2299.1:2007[11]). The New Zealand Maritime Authority requires dive vessels to be in survey and skippers to have the appropriate certification levels. Direct observation of D!T by three of the authors (MH, FMD and SJM) suggests a strong 'safety first' work ethic throughout the company. This could explain the similar low prevalence of treated DCI amongst USA science and D!T divers. Also, because of 'no fault' legislation in New Zealand (Accident Compensation Act 2001 No. 49 and the Health and Safety at Work Act 2015), it is likely that non-diving trauma resulting in injury both to customers and staff was documented accurately and has a relatively low prevalence.

However, there are other factors that may have influenced our measured outcomes. For example, the reference period of the present study corresponds to that over which the findings of the remote DCI workshop in relation to recompression for mild DCI became influential.[12] The workshop's endorsement of treatment without recompression in some cases that met a strict definition of "*mild DCI*" might have influenced decisions by physicians to ascribe alternative diagnoses to the five equivocal cases that were not recompressed (Table 1). Nevertheless, even if these are included in the present analysis as DCI cases, then the calculated rate in our study would be 1:10,000; very similar to several of the other studies. Methodological differences can also account for different results between studies (see above).

What is clear from these various data is that DCI seems relatively uncommon in mainstream recreational scuba diving. This observation segues into consideration of the use to which data of this nature can be put. We would suggest that accurate estimates of the DCI rate derived from large cohorts of divers conducting activity typical of the vast majority of recreational scuba diving are important for purposes such as actuarial evaluations, healthcare resource planning, informing choices of prospective divers and characterizing the safety of the sport in relation to other activities. For example, in 2018, the Mountain Safety Council of New Zealand reported 5,504 tramping injuries in more than 1.5 million trampers; that is, one in 279 trampers needed medical care.[13] Recreational scuba diving in northern New Zealand, by comparison, would appear to be a relatively injury-free adventure activity. The requirement for operators like D!T to maintain accurate recording of diving activity and related incidents that is enshrined in health and safety legislation and adventure sports standards seems justified for this purpose alone.

It needs to be clearly understood, however, that the risk of DCI for an individual diver or dive is extremely context-sensitive and may not conform to 'population estimates'. Even if it is assumed that there are no untoward events on a dive, there are other factors that may significantly alter risk such as the presence of a large persistent foramen ovale (PFO).[14] Water temperature may have a profound influence on DCI risk. For example, in the Project Dive Exploration study, a separate series of 6,527 dives in cold water resulted in a reported DCI rate of 28 per 10,000 dives.[15] The explicit collection and reporting of such dives in Project Dive Exploration will partly explain the increased overall prevalence of DCI reported from that database (Table 2).[3] Some sub-types of 'recreational' scuba diving, such as deeper decompression dives conducted by 'technical' divers may carry a substantially higher risk.

Diving incidents other than DCI and non-diving incidents/injuries were both more common in the present study than DCI. It is much more difficult to benchmark the prevalence of relatively minor non-diving injuries because of a lack of comparable studies. However, it is clear that such injuries accrued in the operation of boats are recognised as important and qualitatively similar to those reported here.[16]

LIMITATIONS

Our data likely under-estimate the true prevalence of mild DCI due to under-reporting. It is well recognised that minor symptoms of DCI are often unappreciated or even concealed by divers. Nevertheless, the number of divers recompressed for DCI is a hard numerator, and any cases not reported (or recompressed) were almost certainly mild. Therefore, our DCI data can be considered a valid indicator of the rate of clinically significant DCI.

In relation to our other injury data, it is widely recognised in medical research that the published prevalence of such events is often strongly influenced by how those outcomes are defined and measured. For example, only two symptomatic middle ear barotraumas were recorded over the seven-year period of the present study, yet a recent study involving prospective examination by expert observers demonstrated middle ear barotrauma in 48 of 67 open-water course trainees.[17] Middle ear barotrauma likely occurred much more often than recorded in our study; in fact, it is sufficiently common that both divers and skippers might not consider it worthy of reporting, unless severe. In a similar vein, the more common (and minor) an event, the less likely it is to be meticulously recorded even if reported to the crew. Therefore, incomplete recording is another potential cause for underestimation of the rate of common minor events. Nevertheless, because of the no-fault injury compensation system in NZ, the recording of non-diving injury requiring either first aid or further medical attention is likely to be fairly reliable.

We must acknowledge the fact that some non-DCI diving-related injuries or complications may not have become apparent for up to days after diving. For example, a recent study that included evaluation of post-diving presentations to American emergency departments suggested that otitis and other infections that could be expected to develop slowly accounted for approximately 16% of consultations.[18] These will not be accounted for in our data.

Finally, this is a single-centre study and the extent to which the DCI prevalence estimate can be generalised across the dive charter industry or recreational diving in general is uncertain. However, as discussed above there is reasonable agreement with estimates from other settings, which is encouraging.

Conclusions

Recreational diving in this temperate water, off-shore environment had a remarkably good safety record given that all levels of diving experience were being catered for. Diving-related injuries were generally minor and uncommon. Staff members appear to have been at more risk of injury than customers. Care in a marine environment needs to be stressed at all times.

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Conflicts of interest

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