Decompression illness in divers treated in Auckland, New Zealand, 1996–2012

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Abstract

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Introduction: The treatment of divers for decompression illness (DCI) in Auckland, New Zealand, has not been described since 1996, and subsequent trends in patient numbers and demographics are unmeasured.

Methods: This was a retrospective audit of DCI cases requiring recompression in Auckland between 01 January 1996 and 31 December 2012. Data describing patient demographics, dive characteristics, presentation of DCI and outcomes were extracted from case notes and facility databases. Trends in annual case numbers were evaluated using Spearman's correlation coefficients (ρ) and compared with trends in entry-level diver certifications. Trends in patient demographics and delay between diving and recompression were evaluated using regression analyses.

Results: There were 520 DCI cases. Annual caseload decreased over the study period (ρ = 0.813, P < 0.0001) as did entry-level diving certifications in New Zealand (ρ = 0.962, P < 0.0001). Mean diver age was 33.6 (95% confidence limits (CI) 32.7 to 34.5) years and age increased (P < 0.0001) over the study period. Median (range) delay to recompression was 2.06 (95% CI 0.02 to 23.6) days, and delay declined over the study period (P = 0.005).

Conclusions: Numbers of DCI cases recompressed in Auckland have declined significantly over the last 17 years. The most plausible explanation is declining diving activity but improvements in diving safety cannot be excluded. The delay between diving and recompression has reduced.

Key words

Diving, embolism, decompression illness, hyperbaric oxygenation therapy, air/diagnosis/etiology/therapy, decompression sickness/diagnosis/epidemiology/etiology/physiopathology/therapy

Introduction

Decompression illness (DCI) may occur following compressed gas dives if intra-corporeal bubbles form from dissolved inert gas, or if air is introduced to the arterial circulation by pulmonary barotrauma. The definitive treatment of DCI involves recompression and oxygen administration in a hyperbaric chamber.[1] Recompression facilities in New Zealand are located in Auckland and Christchurch and these have, in general, served divers from the North and South Islands respectively, although lower North Island divers are sometimes evacuated to Christchurch for recompression. The recompression facility (the Slark Hyperbaric Unit, SHU) in Auckland has been based at the Royal New Zealand Navy Hospital (RNZNH). Another unit, operated by Hyperbaric Health (a private company), has offered treatment for DCI since 2006. The caseload of the SHU was last reported for the 1996 calendar year.[2]

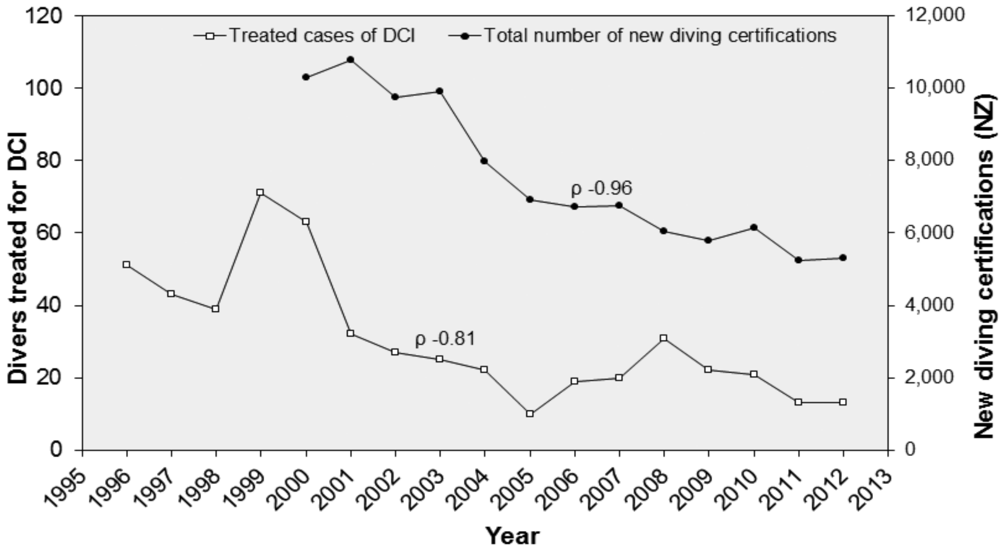
We undertook this study to describe the numbers and characteristics of DCI cases treated in Auckland from 1996 to the present time. In particular, we set out to document any trends in case numbers, and in relevant parameters such as patient demographics, type of diving, and latency between the incident dive and recompression.

Methods

The study was approved by the University of Auckland Human Participants Ethics Committee (Reference: 9287). Locality approval was given by the Royal New Zealand Navy and Hyperbaric Health Limited. This was a retrospective, longitudinal audit of DCI cases treated in Auckland between 01 January 1996 and 31 December 2012. We chose 1996 as the start point because from this year forward the Christchurch unit was in continuous operation and patient numbers were not influenced by the need for evacuations from the South Island. A small number of cases were treated at the Hyperbaric Health Unit from 2006 and so these were also included in the audit.

Scuba divers who were recompressed and given a discharge diagnosis of DCI, probable DCI, or possible DCI were included. Cases considered 'unlikely' to have DCI or given alternative discharge diagnoses were excluded. At the SHU, case data were accessed by the principal author from two sources. The primary source was a Microsoft® Access 2 database maintained by the hyperbaric technicians and updated with each new patient's data during or soon after their admission. Where available, original case notes were also accessed for comparison against the database and extraction of missing or additional parameters. Data for cases treated at the Hyperbaric Health unit were extracted directly

Figure 1
Temporal trends in the number of divers treated for decompression illness in Auckland between 1996 and 2012 ($P < 0.0001$); the temporal trend in the number of newly certified divers (all New Zealand) is also displayed for 2000 to 2012 ($P < 0.0001$)



from case notes by a Hyperbaric Health clinician. Data from both units were combined into a single spreadsheet. Each case was given a unique study identifier. No data were collected that could identify patients or hospital staff.

The following data were extracted for each case: age; gender; height; weight; diver certification level; number of previous dives; maximum depth of incident dive or dive series; method of assessing decompression status during incident dive (dive table, dive computer, nil); breathing gas used (air or nitrox/mixed gases); equipment used (open-circuit scuba, surface supply or rebreather); latency between last dive and symptoms; nature of first-aid treatment; latency between last dive and recompression; qualitative nature of the symptoms; the presence or absence of objective signs on examination; putative risk factors for DCI; initial recompression treatment table; number of follow up recompressions and the recovery status at discharge (categorically divided as complete or incomplete recovery).

In an attempt to compare trends in annual case numbers against an indirect index of diving activity, annual numbers of new diver certifications in New Zealand over the years 2000–2012 were obtained by courtesy of a major global and national provider of diver training, the Professional Association of Diving Instructors (PADI).

This was a descriptive study rather than an investigation of hypotheses. Nevertheless, we identified the measurement of any trend in annual cases recompressed between 1996 and 2012 as the primary endpoint. Secondary endpoints were the trends over time in: maximum depth of the incident dive or dive series; breathing gases used; latency between the incident dive or dive series and recompression and in diver demographics such as age, body mass index (BMI) and gender.

STATISTICAL ANALYSIS

Trends in annual case numbers were investigated using Spearman's *rho* (ρ) correlation coefficients. Trends in secondary outcomes were investigated using regression analyses with year as a covariate. Linear regressions were conducted using normal distributions where appropriate, and Poisson distributions for count data. Binary data were investigated using logistic regression. A P value of < 0.05 is usually considered to indicate statistical significance; however, a total of eight analyses were conducted in this study and therefore the predefined criterion for statistical significance was adjusted using a Bonferroni correction (to $P < 0.00625$). All analyses were conducted using SPSS Statistics V. 19.

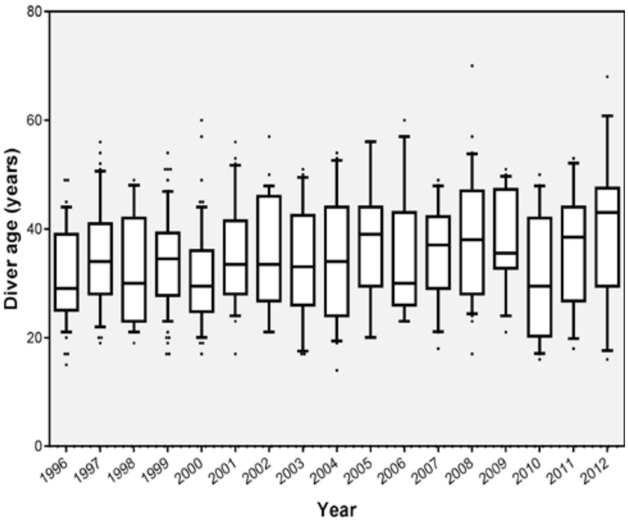
Results

NUMBER OF CASES

A total of 522 divers recompressed for DCI were identified. Two cases were excluded (one was an erroneous entry in the RNZNH database, and a second case was eventually diagnosed as feigned or 'factitious' DCI[3]), leaving a total cohort of 520 cases of which 506 were treated at the SHU and 14 at Hyperbaric Health. The annual DCI case load has trended downward over this period (Spearman's $\rho = 0.813$, $P < 0.0001$). Similarly, new diving certifications issued in New Zealand by PADI have also trended downward over a similar period (2000–2012) (Spearman's $\rho = 0.962$, $P < 0.0001$) (Figure 1).

Figure 2

Age of divers recompressed over the study period; the box plot shows the median (horizontal line inside boxes), interquartile range (boxes), and 10th-90th percentile (vertical lines). Outlier data are indicated by black dots. A significant upward trend in age is shown ($P < 0.0001$).



DIVER AGE, GENDER AND BMI

Demographics and diving characteristics of the recompressed divers are summarised in Table 1. Mean age (95% confidence limits, CI) across the cohort was 33.6 (32.7 to 34.5) years and age increased over the study period ($P < 0.0001$) (Figure 2). No significant trends were identified for gender or BMI over time.

DIVER EXPERIENCE

Certification levels among recreational divers covered a spectrum from no formal certification to instructor. There were also a number of so-called recreational 'technical divers' and occasional divers from professional groups such as commercial and military divers. Fifty-four per cent of divers for whom the previous number of dives was recorded had completed fewer than 100 dives at the time of injury, and 19% had undertaken more than 500 (Table 1).

NATURE OF DIVING

The vast majority of cases of DCI occurred in divers using standard open-circuit scuba equipment (95%), with six (~1%) using rebreathers, and six (~1%) using surface-supply equipment. In 13 cases (~2%) the equipment was not recorded. Of the 496 cases where the diving activity was explicitly recorded, 460 (93%) were diving recreationally, with only three involved in military diving and 33 (~6%) in occupational diving. Note, this distribution of activity does not intuitively match the certification data because some occupational diving (such as diving instruction) is undertaken by divers with recreational qualifications.

Table 1

Demographics and diving experience of 520 divers treated for decompression illness in Auckland between 1996 and 2012

Diver demographics	***n***	**mean**	**range**
Age (yr)	512	34	14–70
Male:Female	419:101		
Weight (kg)	384	83	45–198
Height (cm)	379	178	140–210
BMI (kg m^{-2})	377	26.2	16.5–59.1
Certification level	***n***	**%**	
No certification	24	4.6	
Training	14	2.7	
Basic open water	274	52.7	
Advanced/Rescue/ Dive-master	98	18.8	
Instructor	49	9.4	
Commercial/Military/ Technical	4	0.8	
Unknown	57	11.0	
Experience level	***n***	**%**	
No previous dives	8	1.9	
≤ 5	25	5.8	
≤ 10	29	6.8	
≤ 100	169	39.4	
≤ 500	118	27.5	
> 500	80	18.6	
Breathing gas used	***n***	**%**	
Air diving	488	96.6	
Mixed-gas diving	17	3.4	

The depth of incident dives (or dive series) ranged from 1.8 to 80 metres, with a mean (95% CI) of 25.8 (24.74 to 26.92) m. There were no significant trends over time for depth of incident dive or use of air versus nitrox and mixed gas. There was an apparent increase over time in the proportion of recompressed divers who used a dive computer as the primary method of depth and time control. For example, in 1996 45% of incident dives were controlled according to a table plan whereas 18% were controlled by a computer (37% of divers either used nothing or the planning tool was not recorded). By 2012, this situation had reversed and 46% of divers were controlled by a computer, and 15% according to a table. Unfortunately over the period of the study, many data were missing in relation to this parameter, and we did not attempt to analyse the trend.

RISK FACTORS

In addition to provocative depth/time profiles, a number of putative risk factors for DCI have been proposed. The most prevalent of these among cases in this study was repetitive diving (57%). Rapid ascents (30%), consecutive days' diving

Figure 3

Putative risk factors for DCI among divers recompressed over the study period; data are the percentage of the total cases in which the risk factor was reported

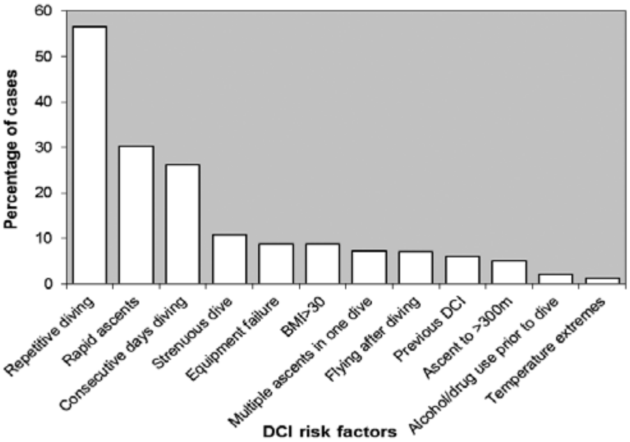
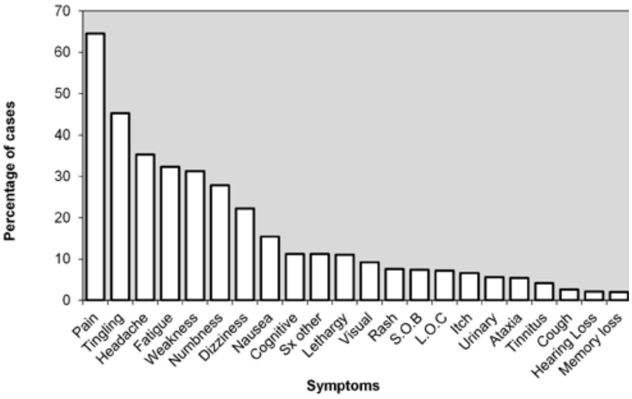


Figure 4

Presenting symptoms of the divers treated over the study period (percentage of the total cases). S.O.B – short of breath. L.O.C – loss of consciousness; 'Cognitive' refers to complaints of dysexecutive problems such as poor memory and difficulty concentrating; 'Weakness' refers to subjective perceptions of weakness (frequently associated with pain but not always associated with objective signs of weakness)



(26%) and subjectively 'strenuous' diving (11%) were also features in many cases (Figure 3).

PRESENTATION OF DCI

The latency of symptom onset ranged from "*present on surfacing*" to 168 hours after diving, with a median time of 1.5 hours. The most frequently reported symptom was musculoskeletal pain (65% of cases), followed by cutaneous tingling (45%), headache (35%), fatigue (32%), weakness (31%), numbness (28%) and dizziness (22%). Objective signs were seen in 180 (36%) of the 499 divers for whom symptoms and objective signs were explicitly recorded. Objective signs included an abnormal sharpened Romberg test.[4] The percentage of cases in which each reported symptom occurred is given in Figure 4.

FIRST AID, REFERRAL AND TREATMENT

In 60% of cases, whether first-aid oxygen was administered was not recorded. Of the 210 (40%) recorded cases, only 87 (41%) received oxygen prior to recompression. Divers were referred mainly by their local doctor (31%), a hospital (30%), or were self-referred (28%). For the entire cohort, the median (range) latency between the incident dive and the time to recompression was 2.06 (0.02–23.6) days. This declined to a small but significant extent over the 17 years audited ($P = 0.005$).

RECOMPRESSION PROTOCOL

In accordance with widely accepted practice, divers underwent an initial recompression prescribed by a protocol chosen according to perceived DCI severity and physician preference. Most commonly this was the US Navy Treatment Table 6, used in 338 (65%) of cases. A 4 ATA (405 kPa) table utilising 50:50 oxygen-helium breathing, the so-called 'RNZN 1A', was prescribed in a further 109 (21%) cases which were generally of a more serious nature. Divers with residual symptoms after the first recompression underwent further once-daily recompressions until there was either full recovery or no sustained improvement over two consecutive days. These follow-up treatments were conducted according to a shorter protocol specifying oxygen breathing at either 284 or 203 kPa for 60 or 90 minutes respectively. The mean number of re-treatments was 1.27.

DIVER OUTCOMES

At discharge, 438 divers (84%) were either without sequelae or with an expectation that minor subjective symptoms would resolve within one month. Though this was usually confirmed by follow-up, these latter cases were deemed to have experienced a complete recovery. Sixty-one (12%) patients were considered to have had an incomplete recovery. Outcome data were not recorded for 21 (4%) divers.

Discussion

We have described the caseload of DCI patients treated in Auckland between 1996 and 2012. The most striking feature of these data is the significant decline in annual case numbers that has occurred over the 17-year period. The mid- to late-1990s was characterised by high numbers of DCI cases treated in Auckland. Indeed, 100 cases were treated in 1995 though this cohort included patients from the South Island because the Christchurch chamber was not operational.[5] Whereas annual numbers above 50 were typical in the 1990s, these have dwindled to fewer than 30 in recent years. There are few published accounts of comparable data from other centres but it is notable that a similar decline in the numbers of divers recompressed for DCI in Australia also occurred between 1995 and 2007.[6] The number of calls from within Australia to the Australian Diver Emergency Service hotline also declined between 1991 and 2007.[7] Thus, the decline in the number of DCI cases treated at Auckland is confluent with the Australian experience. The cause of this decline is unknown.

One potential explanation is that it reflects a regional decrease in diving activity, but the latter has not been measured and it would be difficult to do so.[6] We have reported annual numbers of entry-level certifications issued in New Zealand by the predominant diver training organisation as one plausible index of diving activity over an approximately corresponding period. There has been a significant decline in certification numbers (Figure 1). Similar data were provided by PADI to estimate the incidence rate of scuba diving fatalities for a previous New Zealand study.[8] Although this lends some strength to the hypothesis that the decline in DCI is owing (at least in part) to a decline in diving activity, the observation deserves cautious interpretation. There are other training organisations operating in New Zealand whose training numbers were not obtained, and the number of new certifications cannot be assumed to directly equate with diving activity because this could also be influenced by fluctuations in the activity of previously trained divers, due to factors such as changing economic conditions, or by changes in diving tourism activity.

Another potential explanation is that diving has become safer. The imposition of regulation and safety strategies can produce dramatic declines in DCI cases in high-risk populations, but it is debateable whether there were any pivotal positive influences on diver safety in New Zealand over the reference period.[9] One possibility might be that an increasing proportion of divers adopted the use of dive computers instead of tables for planning and controlling of their depth/time profiles. Computers have several potential advantages such as: ensuring the diver at least uses some means of controlling depth and time; the monitoring of ascent rates and provision of alarms when safe rates are exceeded and avoidance of the errors that divers frequently make when performing dive table calculations.[10] It is known that computer use has increased markedly over the last 20 years to such an extent that, whereas dive table instruction was previously mandatory, the PADI entry level course now offers the option of only learning to use a computer. Little can be deduced from our finding of a trend to increasing computer use among DCI patients without accurate data describing the relative use of computers and tables in the community. The apparent trend in our data probably reflects increasing use of dive computers in the community, and it is possible that dive computer users are actually under-represented in our cohort. Other plausible contributors to improved decompression safety over the audit period include the progressive inculcation of divers in the use of a 'safety stop' for 3 minutes at 5 metres' depth as a routine on every dive. Similarly, relevant educational initiatives such as the SAFE Dive (Slowly Ascend From Every Dive) campaign have become ubiquitous in the instructional and training pedagogy.

A third potential explanation is that fewer divers suffering symptoms of DCI are choosing to present for recompression treatment. This would seem unlikely in the face of serious manifestations, but divers with mild symptoms might invoke the findings of the 2004 remote DCI workshop to justify such a choice.[11] Specifically, a workshop consensus statement reads: "*The workshop acknowledges that some patients with mild symptoms and signs after diving can be treated adequately without recompression. For those with DCI, recovery may be slower in the absence of recompression.*"[11] We doubt this has had significant, if any impact on divers' choices in respect of seeking recompression in New Zealand. Awareness of the workshop's findings among divers is not widespread. In addition, the SHU policy of offering recompression to all local divers diagnosed with DCI has not changed. Moreover, this explanation is not consistent with our data which show that the trend to declining numbers was well established prior to publication of the workshop proceedings in 2005. Finally, if declining case numbers reflected an increasingly frequent choice not to present for mild symptoms, we would expect to see serious cases making up a greater proportion of the total. In fact, the proportion of cases (36%) with objective signs (which tend to be seen in the serious neurological events) is less in this series than the 45% recorded for the 100 cases treated in 1995.[5]

There were several other significant trends revealed by our data. First, the average age of divers treated for DCI increased over the study period. The most plausible explanation for this is that it simply reflects the demographic of the diving population. It is certainly possible that if fewer new divers are being trained (as the PADI data indicate) then a greater proportion of the total diving is being conducted by an aging population of established divers. Second, the median latency between incident dive and recompression also declined over the study period. It is more difficult to generate a plausible hypothesis to explain this trend. The most obvious (but entirely speculative) explanation would be that divers are becoming better educated, such that the diagnosis of DCI has become 'de-stigmatised' and, combined with better understanding on the potential benefits of timely treatment, this has resulted in earlier reporting of symptoms. In respect to evacuation for treatment and since first-aid oxygen can improve the early response to recompression, it was disappointing that in those cases where first-aid strategies were recorded, less than half received first-aid oxygen.

The clinical aspects of the cases in this series were confluent with those reported from a 1995 cohort treated at the SHU.[5] The most common symptoms were pain and patchy paraesthesiae, with objective signs in only 36% of cases. The choice of a higher pressure oxygen/helium table for cases of greater perceived severity is consistent with practice among hyperbaric units in Australia.[12] Most cases (84%) were considered to have made a complete recovery. This was higher than for the 1995 SHU cohort (70%), but the difference is probably explained by changes in the definition of complete recovery at the point of discharge rather than a change in actual outcomes.[5] Over the period considered in the present study mild residual symptoms thought likely to resolve within a month were not considered in determining categorisation as 'incomplete' recovery.

This study has several weaknesses that should be acknowledged. The retrospective method placed reliance on the accuracy and completeness of data recorded in the patient notes and SHU patient database. In some cases, the notes were not available for reconciliation with the database, mandating total reliance on the database. Not surprisingly, there were some missing data. The retrospective design also precluded the accurate application of potentially useful severity scoring systems to individual cases which would have helped inform some of the preceding discussion.[13] Finally, many symptoms of DCI are non-specific and there is an undeniable potential for cautious practitioners to over-apply the diagnosis resulting in contamination of our dataset by non-DCI cases. Such conservative practice is widespread. The 'marginal' cases included in our dataset were recompressed and discharged with the diagnosis of DCI, and by definition they constitute part of the case load. They are, therefore, included in our report. Despite these limitations, our study describes one of the larger single-centre cohorts of DCI patients reported to date in Australia and New Zealand. In addition, the longitudinal design has facilitated identification of several interesting and potentially important trends in the number and nature of cases.

We conclude that the annual number of cases of DCI recompressed at Auckland has declined significantly over the past 17 years. A decrease in diving activity is the most plausible explanation, but other factors cannot be excluded.

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