Scuba diving-related fatalities in New Zealand, 2007 to 2016

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Key words
Cardiovascular; Coroner's findings; Diving deaths; Diving incidents; Drowning; Epidemiology; Obesity

Abstract
(Lippmann J, Lawrence C, Davis M. Scuba diving-related fatalities in New Zealand, 2007 to 2016. Diving and Hyperbaric Medicine. 2021 December 20;51(4):345–354. doi: 10.28920/dhm51.4.345-354. PMID: 34897599.)
Introduction: New Zealand (NZ) diving-related fatalities have been reported since the 1960s. The aim is to identify contributing risk factors, including medical, and to inform appropriate preventative strategies.
Methods: NZ scuba diving fatalities from 2007 to 2016 were searched from multiple sources – the National Coronial Information System (NCIS); the NZ Chief Coroner's office; Water Safety NZ *Drownbase*™ and the NZ Police National Dive Squad records. For inclusion, a victim must have been wearing a scuba set (which may include a rebreather). A key word search of the NCIS was made and the results matched to the other databases. An Excel® database was created and a chain of events analysis (CEA) conducted.
Results: Forty-eight scuba diving fatalities were identified, 40 men and eight women, average age 47 years (range 17–68), 20 of Māori ethnicity. Thirty-five were classified as overweight (14) or obese (21). Pre-existing medical risk factors were identified, either pre dive or at autopsy, in 37 divers, the commonest being ischaemic heart disease (IHD, 20), left ventricular hypertrophy (LVH, 18) and hypertension (seven). IHD, LVH and obesity were variously associated with each other. The likely commonest disabling conditions, identified in 32 cases, were asphyxia (15), cardiac (nine) and pulmonary barotrauma/cerebral arterial gas embolism (five). Multiple environmental and diving practice breaches and poor planning were identified in the CEA, similar to those seen in other studies. Thirty-eight divers had not released their weight belt. Information on resuscitation was limited.
Conclusions: Obesity and cardiovascular disease were common and Māori appear to be over-represented, both as previously reported.

Introduction

With its long and accessible coastline and its diverse underwater environment rich in marine life, scuba diving in New Zealand (NZ) is an attractive recreation. A 2018 online Water Safety NZ (WSNZ) survey of the NZ public reported that 11% of 1,094 respondents had dived or snorkelled in the previous year, although it did not differentiate between these activities.[1] There are few reliable data on the total number of active divers at any given time in NZ,[2,3] although over the study period there were an average of slightly over 5,000 entry-level divers certified annually by the Professional Association of Diving Instructors (PADI; Richardson D, personal communication, June 2021), which likely represents at least 80% of the diver training market in NZ. This has declined from about 6,000 in 2000.[2] This decline would partly reflect the withdrawal of generous government subsidies previously offered to encourage career-related training in the recreational diving industry, as well as a general softening of the industry. Also, it has been reported anecdotally that a relatively high proportion of scuba divers in NZ are uncertified.

Earlier reports have reviewed scuba- and snorkelling-related deaths in NZ from 1961 through 1973,[4,5] 1981–1986,[6–8] 1980–2000[2] and 2000–2006.[9] A recent report by the present authors detailed snorkelling-related deaths from 2007 to 2016.[10] This companion study examines scuba diving-related deaths in NZ waters for the same period with the aim of identifying underlying risk factors, including medical, and of informing appropriate preventative strategies.

Methods

This was a case series of scuba diving fatalities that occurred in NZ waters from 01 January 2007 to 31 December 2016.

For inclusion in this series, a victim must have been reported to have been wearing a scuba set (which may include a rebreather).

ETHICS APPROVAL

Ethics approvals for the collection and reporting of these data were received from the Victorian Department of Justice Human Research Ethics Committee (CF/18/12735) and the NZ Chief Coroner, NZ Department of Justice, to access additional coronial records, WSNZ to access *DrownBase*™ (https://watersafety.org.nz/drowning%20statistics), the NZ Police Research Review and Access Committee (EV-12-531) and the NZ Police Maori Pacific and Ethnic Services to access NZ Police National Dive Squad (NZPNDS) records. The benefits of reviewing multiple data sources have been described previously.[11]

SEARCH

All fatalities reported to NZ coroners since July 2007 have been added to the Australian-based National Coronial Information System (NCIS).[12] A comprehensive key-word search was made of the NCIS for scuba diving-related deaths from 01 July 2007 to 31 December 2016. Key words included scuba, compressed air, compressed gas and div* and underwater fishing. Data obtained from the NCIS was matched with that listed on the Australasian Diving Safety Foundation (ADSF) diving fatality database, the WSNZ *Drownbase*™ (https://watersafety.org.nz/drowning%20statistics), and the NZPNDS diving fatality database to minimise the risk of over- or under-reporting. Coronial data not included on the NCIS (i.e., 1 January to 30 June 2007 and for 'open' cases) were provided by the NZ Ministry of Justice.

REVIEW PROCEDURE

The principal investigator (JL) reviewed all datasets to resolve any discrepancies between the various sources, and then prepared initial incident summaries for each case and created an anonymised, protected Microsoft Excel® spreadsheet. The coronial reports and these summaries were then independently reviewed by each of the co-investigators (CL and MD), any differences in interpretation debated and consensus reached; CL focusing, in particular, on the reported autopsy findings. The NZPNDS records were then hand-searched (MD) to help fill any gaps in the data, especially related to the equipment used. Based on these reviews, the Excel database was finalised.

A chain of events analysis (CEA) was performed for each case using a validated template.[13] Each CEA is based on the evidence in the coronial and autopsy reports. However, in some cases the authors disagreed with the interpretation of the findings, so the disabling agents and disabling injuries reported in the CEAs are based on our consensus interpretations, but the cause of death given is that of the pathologist conducting the autopsy or by the coroner where no autopsy was performed.

OUTCOME MEASURES

A range of outcome measures were extracted. Where available, these included demographics, health factors, training and experience, dive location and conditions, buddy circumstances and oversight, dive purpose and depth, equipment used and resuscitation factors. Then, a possible CEA of each fatal incident was created. Descriptive analyses based on means and standard deviations or medians and ranges, and Mann-Whitney and χ^2 tests for comparisons of age or BMI, as appropriate, were conducted using SPSS Version 25 (IBM Armonk, NY; 2017). The level of statistical significance assumed was $P = 0.05$.

Results

From 01 January 2007 to 31 December of 2016 there was 48 identified scuba diving-related deaths in NZ territorial waters, 40 men and eight women. Forty-seven of the victims used open-circuit scuba and one used a closed-circuit rebreather (CCR).

DEMOGRAPHICS

Ethnicity is documented in NZ and 17 of the 48 divers were NZ residents of European origin, 20 were of Māori ethnicity, whilst ten were tourists (seven of European origin and three Asians) and there was one diver from another Pacific Island. Mean (SD) age was 47 (12) years, and there were no differences in age between the sexes ($P = 0.60$) or between ethnicities ($P = 0.20$). Body mass index (BMI) was available for 43 victims (mean [SD] 29.3 [5.3] $kg{\cdot}m^{-2}$) and was similar between the sexes (29.6 [5.1] $kg{\cdot}m^{-2}$ for 36 men, 28.0 [6.4] $kg.m^{-2}$ for seven women). Thirty-five victims were classified as overweight (14, 12 men and two women; BMI 25–29.9 $kg{\cdot}m^{-2}$) or obese (21, 18 men and three women; BMI ≥ 30 $kg{\cdot}m^{-2}$) (Table 1). Seventeen of the 35 NZ residents for which the BMI was known were classified as obese. There were no statistically significant differences in the actual BMIs between NZ residents of European extraction and Māori victims ($P = 0.60$) or in the BMI classification between these two groups ($P = 0.93$; Table 1).

PRE-EXISTING MEDICAL CONDITIONS AND MEDICATIONS

Eighty-four pre-existing medical or pharmaceutical risk factors were identified as either known pre-dive (55), or found postmortem (29), in 37 of the 48 divers; some divers having more than one risk factor present. Apart from obesity, other known pre-dive health factors were present in over one third of victims. These included ischaemic heart disease (IHD, 10); hypertension (seven); asthma or chronic obstructive pulmonary disease (five); epilepsy (two); use of amphetamines/alcohol (five), depression on antidepressants

Table 1
Body mass index (BMI) classification of 43 scuba fatality victims according to their ethnicity; no data for five divers; $P = 0.93$ for the difference in BMI classification between Māori and New Zealand residents of European extraction

BMI ($kg \cdot m^{-2}$)	Māori ($n = 18$)	NZ European ($n = 16$)	Others ($n = 10$)
Normal (18.5–24.9)	2	2	4
Overweight (25–29.9)	6	6	2
Obese (≥ 30)	9	8	4
Mean (SD)	30.4 (6.4)	29.1 (3.6)	27.7 (5.3)

(three) and one diver with non-insulin-dependent diabetes mellitus. At autopsy, a further 10 cases of IHD and 18 divers with left ventricular hypertrophy or cardiomegaly (including the seven with known hypertension) were identified. One diver had a history of shortness of breath whilst diving, suggestive of previous immersion pulmonary oedema (IPO).

Whether or not victims were taking medications was documented in the coronial reports for only 17 divers. Generally poorly documented in the coronial reports, the recording of such data appeared to improve in the final two years of the study. Anti-hypertensives (seven); anti-depressants (three); bronchodilator inhalers (three), anti-epileptics (two) and allopurinol and analgesics were noted. Methamphetamine, cannabis metabolites and/or alcohol were identified in the blood of five divers, four of whom had other medical risk factors present as well.

CERTIFICATIONS AND EXPERIENCE

Thirty (21 non-Māori and nine Māori) of the victims were recorded as having received some form of diver certification, usually Open Water Diver (OWD). At least six divers had been certified as Advanced Open Water Diver (AOWD or equivalent), and there were two instructors. At least eight of the victims were uncertified, five of them Māori. No information about certification was available in 10 cases, six of them Māori. Most reports included very little pertinent information regarding 'experience' other than comments from family, buddies or investigating officers. Based on these, 22 divers were classified (often subjectively) as 'experienced'; four were defined as 'novices', three divers had no experience at all and there was insufficient information to make any determination in one case.

LOCATION AND SETTING

Thirty-nine of the incidents occurred in the North Island and the remaining nine in the South Island. Nine incidents occurred in a commercial setting, either on dive charters and/or during training. The other 39 incidents occurred during private diving activities.

BUDDY AND SUPERVISION CIRCUMSTANCES

In the 46 incidents where the buddy circumstances were clear, 17 divers had set out solo, 17 had separated from their buddy or group before the incident, three separated during the incident and the remaining nine were still with a buddy or group. Māori victims were five times more likely to have been solo diving than their non-Māori counterparts (OR = 4.9 [95% CI 1.24, 19.46], $P = 0.02$). There was no information about supervision in one incident; however, 34 divers were supposedly under some supervision and 13 were unsupervised.

DIVE PURPOSE

The activity was unknown for one incident. Twenty-nine victims were harvesting seafood; other activities included sightseeing (eight), tasks associated with boats (three), wreck diving (two) and training (five). Three of the training-related deaths occurred during AOWD training or equivalent, including a double fatality in a freshwater lake with a depth of 54 msw. These two victims separated from the group in poor visibility. The other AOWD incident was due to a medical issue not directly related to training or skills. Another death occurred during the initial check-out dive of a commercial training course, when the diver became separated from the group in low visibility. This diver who was from the tropics had failed to complete the prior swim tests due to the cold. There was also one death during a Discover Scuba Diving (DSD) experience. The instructor had requested that the student make her way to shore while he continued to dive with another diver. The victim was later found deceased, with her BCD inflated and an empty tank.

DEPTH OF DIVE AND INCIDENT

The maximum dive depth recorded in 43 cases ranged from 2 to 67 metres (median [IQR] 11 [7, 19] metres). Only six of the fatal dives were to 30 metres or deeper. Twenty-seven incidents likely occurred underwater, with at least six of these during ascent, and 13 incidents were reported to have occurred on the surface before or after the dive. One diver collapsed after returning home from a dive on which he had felt unwell; this death was included as being diving-related. There were insufficient data to determine incident depth in seven cases.

DIVE SUITS, WEIGHTING AND BUOYANCY COMPENSATORS

Forty-four divers had worn wetsuits and one (the CCR diver) a drysuit. One diver only wore shorts and t-shirt despite carrying 9 kg of weights. There were no data in two cases. At least 38 divers were found still wearing their weights,

five had ditched their belts, and one diver had ditched only one of two pockets of integrated weights. The amount of weight carried was recorded in 29 cases, and ranged from 7 to 19.2 kg, with mean (SD) of 12.6 (2.8) kg. The NZPNDS investigations suggested that at least 15 of the victims were overweighted. At least three of the divers were not wearing a buoyancy compensator device (BCD) during the dive, instead wearing cylinders with backpacks. All these carried weight belts (with weights ranging from around 8 to 19 kg). Of the 44 divers whose incident occurred at sea and who were wearing a BCD, eight were found with an inflated BCD; 24 divers' BCDs were not inflated and in 12 cases the state of BCD inflation was not reported.

BREATHING GAS SUPPLY

One diver was using a CCR and the remainder used open circuit scuba. The CCR diver used trimix and at least 46 of the others were breathing air. At least 17 of the victims had exhausted or near-exhausted their breathing gas supply, whilst 25 had sufficient remaining air to surface safely. In six cases, the air supply circumstances were unstated, and in one not applicable (a diver who died at home). Analysis of the remaining gas was available in 22 cases. One cylinder was reported to be slightly contaminated with methane and carbon monoxide, although these were not considered to be contributory by the police. Another contained 900 ppm of carbon dioxide (acceptable level 480 ppm).[14] A higher than recommended water vapour content was found in 16 cylinders.

EQUIPMENT FAULTS

Equipment was tested by the NZNPDS in at least 41 cases and faults, sometimes minor, were identified in 25 of these. In 11 cases, faults were assessed as being contributory to the incident, and possibly contributory to another eight. The main problems identified were with demand valves (e.g., faulty/ill-fitting mouthpieces or diaphragms causing 'wet breathing', high breathing resistance or free flowing), BCDs (poor fit, leaks, faulty inflators), inaccurate gauges, overweighting and weight belts that could not be released easily in an emergency. Of note, the bodies of six divers were found with their catch bag still attached to their BCD or weight belt.

RESCUE AND FIRST AID

A rescue attempt (i.e., the victim was accessed and landed relatively quickly, with an arguable possibility of survival) was made in 25 of the incidents. It was reported that in-water rescue breathing was performed in at least two of these. At least 22 of 38 divers still wearing their weight belt had to be searched for and recovered from underwater, introducing substantial delays and reducing the likelihood of survival irrespective of any resuscitation attempts. There was generally very little information about the first aid provided, other than whether basic life support (BLS) was performed. BLS was attempted in at least 27 incidents but withheld in two when possibly reasonable to have been performed. Resuscitation was not appropriate in 16 cases due to extended delays. There was no information in three cases. Only five reports included a mention of airway complications, which included frothy sputum (three) and regurgitated stomach contents (two). The use of a defibrillator was only mentioned in two reports. Both were used by medical responders, rather than anyone involved with the dive, and after considerable delays. The presenting rhythm, or if any shock was delivered, was not indicated in either report. Information about whether oxygen was available at the site was sparse, and oxygen was only mentioned in three reports, all of these in a commercial setting. In two cases, it was used during resuscitation. In the third, the report mentioned that the distressed diver had asked for oxygen and a crew member looked for a '*bottle*'.

AUTOPSIES

Where there was a delay in recovery of the body, particularly in the South Island with significant sea lice activity, extensive soft tissue loss in three cases severely limited the contribution that the autopsy made to the determination of cause of death. No body was recovered in one case.

As in the companion report on snorkellers,[10] IHD (20), left ventricular hypertrophy (18), and obesity (21) were present at autopsy and represented health risks to diving. In all 18 divers with LVH or cardiomegaly, this was undiagnosed pre dive, whilst known hypertension was present in seven. Undiagnosed IHD was present in 10 cases.

Methamphetamine was detected in blood from four divers. These divers all had other medical risk factors: one had IHD; one had cannabis and IHD; one had cannabis and LVH and one had cannabis and epilepsy.

CHAIN OF EVENTS ANALYSIS

Predisposing factor (PF)

There were 113 possible or likely PFs identified in the 48 incidents (Table 2). Medical conditions are discussed above. Approximately one half of the PFs could be classified as deviations from accepted safe diving practice (e.g., diving under the influence of recreational drugs, diving solo, diving with inadequate or faulty equipment among others). Equipment faults included poorly adjusted or leaking demand valves (seven), faulty contents gauges (three) and faulty BCDs (three). Inappropriate equipment included ill-fitting fins (three), over-tight wetsuits (two), an overly large BCD and a weight belt secured by a harness which made it impossible to release in an emergency. Absent equipment which might have prevented the incident or changed the outcome included a BCD (two), knife (two), torch (two), fin (one), wetsuit (one) and secondary demand valve.

Table 2
Predisposing factors (n = 113) associated with 48 scuba fatalities; some deaths involved multiple predisposing factors. * Some of these 24 equipment incidents involved multiple faults or omissions; CCR – closed-circuit rebreather

Predisposing factors (n divers)	**Subgroup**	**Number of factors**
Health (n = 37)	Significant medical condition(s)	29
	Drug/alcohol intake	5
	Obesity only	3
Absence of appropriate equipment or use of faulty equipment* (n = 24)	Overweighted	15
	Faults	10
	Absence	5
	Other	9
Planning (n = 24)	Solo diving	15
	Poor choice of dive site	3
	Adverse conditions	3
	Poor buddy system	2
	Poor air planning	1
Training/experience/skills (n = 12)	Lack of skills and/or experience for dive	7
	No recent experience	3
	Untrained and inexperienced	2
Activity (n = 5)	Deep diving in zero visibility and beyond experience	2
	Deep, working dive on CCR	1
	Deeper dive hunting crayfish	1
	Removal of scuba in strong surge	1
Organisational (n = 4)	Poor choice of site in conditions	3
	Failure to check certification	1
Poor supervision by: (n = 3)	Divemaster	1
	Instructor	1
	Boat operator	1
Other (n = 4)	Poor communication	2
	Poor attitude	2

The main planning factor was a decision to dive solo or intentionally separating during the dive. In two incidents, the separation, though not anticipated, occurred directly because of an intentionally loose buddy system. A poor choice of dive site (a lake with a depth of 54 metres and low visibility at depth) contributed to the deaths of two students during an AOWD course; they were easily able to disappear and exceed the planned depth of 39 metres. In at least three cases, the victims did not recognise that the prevailing conditions were beyond their capabilities, especially given they were diving solo. One diver started a solo dive with only 50 bar of air in his tank and ran out of air.

Training, experience and/or skills-related PFs were identified in 12 incidents, which included the training-related deaths described earlier. Four of the five activity-related deaths were associated with deeper diving. These included the double fatality, another diver possibly ran out of air while hunting crayfish at 40 metres' depth, whilst the CCR diver was working hard at depth. The fifth victim did an out-of-air ascent after removing his scuba unit to enter a cave in a strong surge.

Organisational factors included poor matching of the dive site to the skills and/or experience of the divers. These included the double training fatality and the diver participating in commercial diver training. Another diver was highly inexperienced and likely uncertified and the dive operator failed to take this into account. Incidents involving poor supervision included a divemaster who allowed an inexperienced diver to dive in poor conditions and lost sight of him, an instructor who requested the DSD participant to make their way to shore without supervision and a boat operator who failed to disengage the boat's propeller when a diver entered the water. Poor communication is likely present in many diving mishaps but was obvious in two cases; one involving three CCR divers working together underwater to raise a heavy object and the other the boat propeller incident. The incident in which a poor attitude was evident involved the two student divers who reportedly tried to race each other to the bottom of the deep lake.

Triggers

Gas supply triggers, running out of or very low on air, were implicated in at least 17 incidents (Table 3). In 14 of these, the victim was either solo (six), or had separated from their buddy prior to the incident (eight). There was no statistical association between harvesting seafood and running out of air (OR = 2.2. [95% CI 0.60, 8.13], P = 0.23).

Table 3
Triggers associated with 48 scuba fatalities; some deaths were associated with multiple triggers

Triggers	Subgroup	*n*
Gas supply (*n* = 17)	Out of gas	13
	Low gas	3
	Loss of regulator	1
Environmental (*n* = 17)	Immersion effects	10
	Conditions	4
	Narcosis	2
	Entrapment	1
Exertion (*n* = 8)	During dive	6
	Pre dive	1
	Post dive	1
Equipment (*n* = 2)	Various	2
Buoyancy (*n* = 1)	Excessively overweighted	1
Primary diver error (*n* = 1)	Entered with propellor engaged	1
Unknown (*n* = 8)	–	8

Ten of the environmental triggers were believed to have arisen from the direct effects of immersion, which can impact cardiac function and lead to cardiac arrhythmias in susceptible persons. Conditions such as swell, surge, current, poor visibility and cold were also implicated in incidents, in some cases compounding the effects of immersion. Of the eight cases identified with likely exertion triggers, six of the divers were obese, four were carrying heavy catch bags, two were taking beta blockers (known to reduce exercise tolerance), at least three had stiff demand valves and at least one was substantially overweighted for the dive. Cardiac conditions were identified as the disabling agents in at least four, possibly six of these incidents.

Although equipment deficiencies were apparent and likely contributory to some incidents, they were only identified as direct triggers in two. One perforated demand valve diaphragm caused aspiration and a likely subsequent asthma event. The collapse of a surface marker buoy being used to lift a heavy object caused the loss of the ascent shot line and subsequent complications during ascent from a deep dive (the CCR diver).

Disabling agent (DA)

Medical factors, predominantly cardiac-related (11), but also epilepsy (two), asthma (two), IPO (one) and methamphetamine toxicity (one) were identified as the main likely DA (Figure 1). The gas-related DAs all involved exhaustion of breathing air supply. The buoyancy problems were related to being negatively buoyant from overweighting, the absence of or lack of a properly functioning BCD and/or

Figure 1
Pareto chart of disabling agents associated with 39 of 47 scuba fatalities; one occurred on land post dive and in eight cases, no disabling agent could be identified. In some fatalities more than one possible disabling agent was present. The blue line represents cumulative percentage

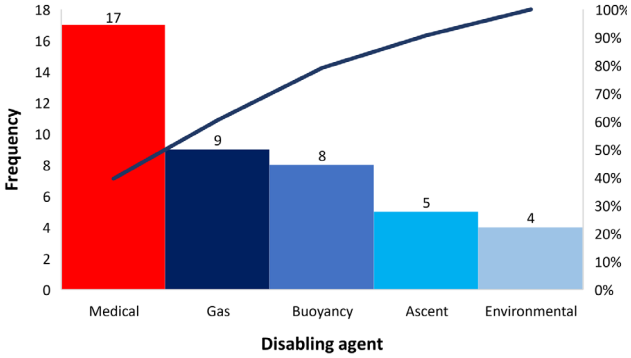
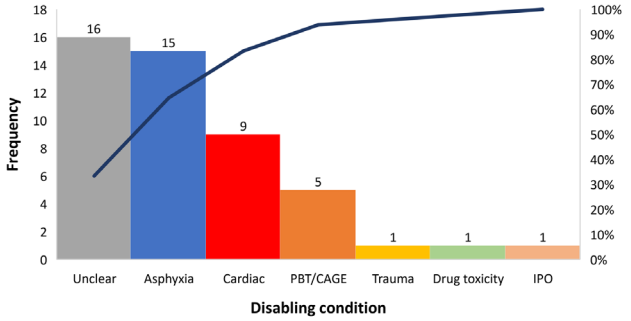


Figure 2
Pareto chart of disabling conditions in 48 scuba diving fatalities; the blue line represents cumulative percentage. IPO – Immersion pulmonary oedema; PBT/CAGE – pulmonary barotrauma/cerebral arterial gas embolism. The blue line represents cumulative percentage



carrying a heavy catch bag. The ascent-related issues arose from out-of-gas ascents leading to pulmonary barotrauma (PBT) and cerebral arterial gas embolism (CAGE). The environment-related DAs included adverse conditions, entrapment and contact with a boat propeller.

Disabling condition (DC)

The predominant DCs identified were asphyxia, cardiac causes and CAGE with or without evidence of PBT (Figure 2). Others included IPO (one), trauma (one) and likely methamphetamine toxicity (one). In 16 cases, no clear DC could be identified. In six of these, there were indicators of a possible cardiac-related incident, although other factors, such as signs of drowning or CAGE, hampered a clear determination. PBT with CAGE was a possible disabling condition in another six incidents although the evidence was unclear and there were also indications of possible drowning.

Discussion

DEMOGRAPHICS AND MEDICAL CONDITIONS

PADI, which is the largest recreational diving instruction agency in the world, reported that, over much of the period of this study, the ratio of male to female recreational entry-level divers certified worldwide by PADI was roughly two-thirds to one-third.[15] However, certification data may not reflect the actual proportions of the sexes diving in NZ as a substantial proportion of NZ divers appear to be uncertified, and there is anecdotal evidence that uncertified divers are predominantly male. Nevertheless, the proportion of female divers in this (8/48) and previous NZ fatality series (23 of 174, 13%)[2,9] would seem to be less than expected on the basis of their level of diving activity.

The mean age of NZ diving fatalities has increased from 34 years in the 1980–2000 study[2] by over a decade, to 47 years. Whilst the average age in the present series is similar to that of contemporaneous fatalities amongst DAN America members,[16] other reports suggest the average age of divers at certification is in the mid-30s, with more active divers aged in their mid-40s to 50s.[15,17] These data are consistent with the apparent increase in deaths of older divers with important medical co-morbidities.

In those victims where BMI was known, one half were obese, irrespective of ethnicity, with the prevalence of obesity in the general adult NZ population being reported as 48% and 29% in Māori and non-Māori respectively.[18] Although the numbers in this study are small and need to be interpreted cautiously, the proportion of obese non-Māori fatality victims was higher than the general population. Obesity was reported as a possible risk factor in cardiac-related diving deaths in Australia,[19] and in one third of the NZ divers, both obesity and cardiac disease were present.

Examining *DrownBase*™ reveals that between 2015 and 2019, almost one-fifth (18%) of all drownings were associated with alcohol and/or drug consumption. In the present series, alcohol or drugs were likely risk factors or a direct cause of death in five of 47 deaths (one body missing). Numbers are too small, and the study relates to an earlier time period, to determine whether this plays less of a role in scuba-related drownings than overall in drowning deaths in NZ. However, the prevalence appears not to have changed from that of the 1980–2000 NZ series (10/123 scuba divers).[2]

AUTOPSIES

Previously unrecognised LVH was present in 18 divers at autopsy, likely related to obesity and hypertension,[20] and previously unrecognised IHD in ten. There is an extensive literature studying the links between LVH, sustained arrhythmias and sudden cardiac death.[21] A recent review summarising the basic scientific and clinical data for this concluded that "*overall there appears to be a dearth of trials confirming association between hypertensive LVH and progression to sustained* [ventricular arrhythmias] *and sudden cardiac death*".[22] The prevalence of LVH in a Scandinavian population study was 14.9% in males on echocardiography, with BMI and hypertension being the most pronounced independent risk factors.[20]

Within a diving context, a comparative study reported that LVH was significantly greater in 100 scuba diving fatalities than in 178 reasonably matched traffic fatalities taken from a USA database.[23] In an Australian series from 2001 to 2013, LVH was documented at autopsy in 24 (20%) of 126 victims, especially in association with hypertension.[24] In a recent open-water study, five of 60 divers undergoing echocardiography had evidence of LVH.[25] Therefore, the presence of LVH in 17 of 43 autopsies (four unreliable autopsies and one body missing) in the present series is of serious concern. It remains difficult to assess the relative contribution of cardiovascular events in drowning due to the lack of a definitive postmortem test to confirm whether an arrhythmia has occurred. However, the presence of cardiovascular disease increases the risks of sudden arrhythmias and is likely to reduce the chances of the victim's survival.

Despite the increasing availability of computed tomography (CT) scans pre autopsy, it is often not possible to perform a post-mortem CT scan within the first three hours after death. As the pre-scan interval extends beyond this, the distinction between gas embolism and postmortem decompression artefact at autopsy becomes increasingly difficult, if not impossible.[26] Thus, the diagnosis of CAGE at autopsy remains problematic in this series despite five cases having histories suggestive of CAGE. However, in the 49 autopsies in the 1980–2000 series considered to have been performed to the Royal Australasian College of Physicians guidelines,[2,27] CAGE was given as the cause of death in 27 divers – a much higher proportion than in the present study.

The presence of methamphetamine in four cases is disturbing, particularly in combination with cannabis, IHD, LVH and epilepsy. Methamphetamine is highly arrhythmogenic and in a person with ischaemic heart disease, cardiomegaly and LVH would be regarded by a forensic pathologist as a significant contributor to death from a cardiac event.

NZ has both forensic pathologists and regional anatomical pathologists who perform coronial autopsies. Whilst the standard of autopsy reports has improved compared with the 1980–2000 NZ study when only half the autopsies were performed to the guidelines for scuba diving autopsy procedures,[2,27] there were two autopsies by regional pathologists which were considered not to have met the recommended guidelines. Whenever possible, autopsies

of scuba diving deaths should be performed by a trained forensic pathologist in order to extract the best information on the possible cause(s) of and contributor(s) to death.

DIVING CERTIFICATION AND EXPERIENCE

It is difficult to effectively define 'experience' as this depends on many factors, including dives done, time of accumulation and currency, among others. As a result, our classification of 22 divers as 'experienced' was often subjective. Of note, most deaths in the training/experience/skills category were likely a result of primary drowning or CAGE, unsurprising in inexperienced divers. In the 1980–2000 NZ series,[2] lack of diving qualifications and/or experience were common. In the present series, whilst three-quarters of the non-Māori divers had evidence of some form of dive training certification, this was the case in only half the Māori divers. Again, the numbers are small, but this does suggest that increasing formal training in scuba diving amongst Māori men, in particular, may be worthwhile to improve diving safety. It is debated as to whether legislation to prevent unqualified diving would help in this regard (e.g., dive centres and filling stations legally required to demand evidence of a diving certificate before selling or hiring diving equipment or filling cylinders).

Twenty of the 48 divers were of Māori ethnicity, whereas in 2012 (the middle of this study) 16.5% of the general NZ population were recorded as Māori. As was noted for breath-hold/snorkelling deaths over the same period,[10] Māori appear to be over-represented in these fatality data. This is in slight contrast to the 1980–2000 study in which only 23 of 123 divers (19%) were Māori.[2] At that time, fatalities in Māori tended to be more amongst snorkellers (21 of 61).[2] Poorer health, greater uptake but less formal scuba training and deviation from accepted scuba diving practices seem to be specific risk factors for this community. The latter was particularly highlighted by the relative frequency of solo diving in this cohort.

Deviation from accepted scuba diving practices has been highlighted as a problem elsewhere.[28] In that study of 122 divers, "*divers who died from something other than a medical cause were seven times as likely to have one or more violations associated with the fatality*".[28]

SETTING AND PURPOSE

Unlike in Australia where almost half of scuba deaths occurred in a commercial setting,[19] a far higher proportion (39/48) of the deaths in this series occurred in a private setting. This suggests that more NZ divers undertake private diving but there appear to be no published data to confirm this. In theory, diving in a commercial setting should be safer due to the availability of professional supervision. However, deaths can and do occur despite this, as evidenced by Australian data.[19] The activities of the NZ victims also differed from the Australian victims, in that a much higher proportion (29/48) were harvesting seafood compared to Australia (18%) at the time of their demise. Divers can easily become distracted when harvesting seafood and fail to closely monitor their air supply and surroundings. Although there was no association found between harvesting seafood and running out of air, this is based on small numbers. Another marked difference in diving practice was the more than threefold higher proportion of NZ divers who set out solo compared to their Australian counterparts.[19] Although the prevalence of solo diving in NZ victims has fallen substantially over the years (half compared to 78% in 1980–2000)[2] it remains higher than reported in the United States (USA 9%)[29] and the United Kingdom (UK 18.5%).[30]

WEIGHTS, BCD AND GAS SUPPLY MANAGEMENT

Carrying excess weights affects buoyancy management and leads to additional exertion and air usage. Almost one third of divers were considered by the NZPNDS to have been overweighted. Correct weighting and buoyancy control skills are important requirements for safe diving, and divers should strive to achieve these. Overweighting was assessed as the primary causal factor in 5.7% of a series of 140 diving deaths in the UK.[30] In addition, it is important for divers to try to reach the surface in an emergency, rather than become unconscious and need to be found and recovered from underwater.[31] To this end, it is usually necessary to inflate the BCD and/or ditch weights. In NZ fatalities, 159 of 173 divers (92%) between 1980 and 2016 had not released their weights,[2,9] whilst in Australian fatalities, around one half had uninflated BCDs and 82% still had their weights in situ.[19]

Of the 41 cases where details of the remaining breathing gas supply were available, 17 divers had exhausted or near-exhausted their supply. This is consistent with Australian data where more than 40% of victims were completely or almost out of gas;[19] albeit higher than earlier reports from the USA (21%)[29] and the UK (8.6%).[30] These data highlight an ongoing problem of divers failing to adequately monitor their breathing gas and leave sufficient to surface safely. Despite being a fundamental and obvious requirement for diving with scuba, it appears to require continual reinforcement. The high number of cylinders recorded with elevated water content raises concerns about compressor maintenance and the regularity of replacing or correctly repacking the water filters. In NZ, the NZ Underwater Association (NZUA) is contacted by Worksafe to monitor commercial air filling stations but there is no check on privately-owned compressors.

FIRST AID

Little or no information is included in the police or coronial reports regarding first aid, including oxygen provision, defibrillator usage and ambulance management. A similar paucity of information on rescue and resuscitation was reported in a 13-year Australian series.[32] Improved data

collection and recording by official on-site investigators, preferably with knowledge of diving, would better inform potential or necessary improvements.

POLICE INVESTIGATIONS

The NZ National Police Diving Squad investigates and reports on almost all scuba fatalities in New Zealand. This is possible because of New Zealand's comparatively small population and enables consistency in such reports. The reports, which follow a fixed format developed in the early 2000s, are generally of a high standard and provide valuable information, including a review of the circumstances of the incident, extensive equipment reports and gas analyses. Summaries of these appear in many of the published coroner's findings.

LIMITATIONS

Even using multiple sources, it is possible that some fatalities were not recorded due to limitations in recording and NCIS searches. In previous studies,[2,4–9] a few cases in which the cause of death was not recorded as 'drowning', and not documented in WSNZ's *Drownbase*™, may have been missed, but the current search was wider than for those studies. Information from immersion incidents is notoriously patchy and incomplete; especially when unwitnessed. However, in this series, the majority of the coronial and autopsy reports were quite detailed and provided good insight into what likely happened. Health records were often deficient, so there is a strong subjective element to determining what personal factors contributing to a death were important. The CEA attempts to identify the predominant features of each case, but there always remains an element of uncertainty. Nevertheless, some clear lessons can be learned, such as the high frequencies of pre-existing deleterious medical conditions, the contribution of environmental conditions and/or poor diving practices and the apparent disproportionate number of Māori.

Conclusions

Forty-eight scuba fatalities occurred in NZ between 2007 and 2016 in victims of an average age of 47 years. Numerous pre-dive risk factors, both medical and non-medical were present in these incidents. Multiple environmental factors, poor planning, and diving practice breeches were identified in the CEA, similar to those seen in some other studies. Solo diving or separation from dive buddies was a common feature. Thirty-eight divers had not released their weight belt. Information on resuscitation was limited. Obesity and cardiovascular disease were common, and Māori appear to be over-represented, both as reported in previous NZ studies.

Recommendations

- Dive training agencies need to improve training for emergencies, particularly the release of the weight belt. This remains a highly unsatisfactory part of recreational dive training.
- More emphasis during training needs to be placed on breathing gas management and the importance of a good buddy system.
- Middle-aged and elderly, overweight males, especially those with hypertension, are at greatest risk from scuba diving and need to undergo thorough, regular medical assessment, preferably by doctors with knowledge of diving medicine.
- More emphasis on diving safety (both snorkelling and scuba) is needed for Māori in the current water safety programmes of WSNZ and its partners.
- Legislation requiring evidence of diving certification before selling or hiring dive equipment or filling diving cylinders should be considered.
- There is still room for improvement in the documentation of diving fatalities, including obtaining autopsies in as timely a manner as possible; all diving autopsies should be performed by a forensic pathologist.
- The NZUA and worksafe need to review why the air in many cylinders, including from registered filling stations that they monitor, had water vapour levels that exceeded the recommended standard.

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Acknowledgements

National Coronial Information System; Office of the New Zealand Chief Coroner, Ministry of Justice, New Zealand; Coronial Services Unit, Ministry of Justice, New Zealand; Senior Sergeant Bruce Adams and Constables Aaron Wynyard, New Zealand Police National Dive Squad and Water Safety New Zealand for their assistance in the provision and ready access to coronial and other records.

Conflicts of interest and funding

Support was received from the Australian Diving Safety Foundation (Grant 140520, reviewed by trustees other than JL) for travel expenses to review files at the NZ Police National Diving Squad Headquarters, Wellington. Dr John Lippmann is the Chairman of the Australian Diving Safety Foundation. Associate Professor Michael Davis is on the Editorial Board of Diving and Hyperbaric Medicine Journal, but played no part in review of or decision to publish this manuscript. Dr Lawrence declared no conflicts of interest.

Submitted: 05 July 2021
Accepted after revision: 24 September 2021