Snorkelling and breath-hold diving fatalities in Australia, 2001 to 2013. Demographics, characteristics and chain of events

John Lippmann[1,2]

[1] *DAN Asia-Pacific Foundation / Australasian Diving Safety Foundation, Ashburton, Victoria, Australia*
[2] *Department of Public Health and Preventative Medicine, Monash University, Victoria, Australia*

Corresponding author: *John Lippmann, DAN Asia-Pacific Foundation / Australasian Diving Safety Foundation, PO Box 478, Canterbury, VIC 3126, Australia*
johnl@adsf.org.au

Key words
Breath-hold diving; DAN – Divers Alert Network; Diving deaths; Fatalities; Immersion; Snorkelling

Abstract
(Lippmann J. Snorkelling and breath-hold diving fatalities in Australia, 2001 to 2013. Demographics, characteristics and chain of events. Diving and Hyperbaric Medicine. 2019 September 30;49(3):192–203. doi: 10.28920/dhm49.3.192-203. PMID: 31523794.)
Introduction: The aim of this study was to identify characteristics of victims of fatal snorkelling and breath-hold diving accidents in Australia from 2001–2013, inclusive, to determine underlying factors and risks associated with such activities and inform appropriate countermeasures.
Methods: The National Coronial Information System (NCIS) was searched to identify snorkelling and breath-hold diving-related cases reported to Australian coroners for the years 2001–2013, inclusive. Coronial data in the form of findings, witness and police reports, medical histories and autopsies were collected and collated, and descriptive statistics were used to analyse these data. A chain of events analysis was used to determine the likely sequence of events.
Results: There were 175 identified snorkelling-related fatalities during the study period. Most victims were middle-aged males (mean age 49 years). Pre-existing health conditions were possible contributors to 41% of the deaths, the main being ischaemic heart disease. The majority of deaths occurred in Queensland in inexperienced snorkellers, often in commercial settings. The victim's plight often went unnoticed as they were alone, or poorly supervised, when the incident occurred. Apnoeic hypoxia appeared to have been associated with at least 12.5% of the deaths. The main disabling injuries were asphyxia (40%) and cardiac incidents (35%).
Conclusion: Human factors, such as chronic health conditions, poor skills and inexperience and poor planning can play a substantial role throughout the chain of events leading to a snorkelling fatality. It is important to educate the community, doctors and dive industry professionals about potential problems associated with the interaction between certain health-related conditions, especially cardiovascular conditions, and snorkelling. Close supervision is strongly recommended for inexperienced snorkellers due to their likely poor skills, as well as for experienced breath-hold divers due to the potential for apnoeic hypoxia.

Introduction

Snorkelling involves a person breathing through a shaped breathing tube (snorkel) while swimming. A mask for underwater vision, and, often, fins for propulsion are also worn. In addition to swimming on the surface (surface snorkelling), snorkelling may also involve breath-hold diving underwater.

Although the origins of snorkelling are unclear, archaeological evidence suggests that humans were breath-hold diving for shells, and probably food, as early as 4500 BC.[1] Snorkelling has become a popular recreational activity in parts of Australia, especially on the tropical reefs of northern Queensland and Western Australia. There is a dearth of reliable data on the level of snorkelling activity nationwide. A recent report estimated that there were 0.4 million 'frequent snorkellers' (at least once a month) nationally.[2] However, this was based on a very small sample size and is likely to be unreliable; in the author's view, an overestimate of the activity of Australian residents. There is little doubt that the bulk of the snorkelling activity in Australia occurs in Queensland. A survey of domestic and international visitors to Queensland estimated that approximately 1.2 million tourists (half of them from overseas) performed an estimated total of 2.3 million individual snorkel dives (both surface and breath-hold) in Queensland over the 12-month period from April 2006.[3]

Snorkelling can involve a variety of environmental, skills-related, physical, psychological and medical challenges and inevitably results in some associated morbidity and mortality.[4] The Australasian Diving Safety Foundation (ADSF), and before it, the Divers Alert Network Asia-Pacific (DAN AP) and Project Stickybeak,[5] have compiled and maintained a database of identified diving-related fatalities

Table 1
Age measures (in years) of snorkelling victims, 1965–2013

Measure	All (*n* = 337)	Male (*n* = 289)	Female (*n* = 48)
Mean (SD)	43.4 (19.6)	42.3 (19.6)	50 (18.5)
Median (IQR)	40 (26, 61)	39 (26, 59)	57.5 (31, 66)
Range	8 to 85	8 to 85	16 to 80
% ≥ 50	39	36	60

since 1965, including those involving surface snorkelling and breath-hold diving (using some related equipment) in Australia.[6]

Earlier epidemiological reports have analyzed periodic snorkelling fatality data from 1987 to 1996[7] and 1994 to 2006.[8] The author collected all relevant coronial data for 2001 to 2013 and these are analyzed here. The aim of this study was to identify characteristics of victims of fatal snorkelling (i.e., both surface snorkelling and breath-hold diving) accidents in Australia, to identify underlying factors and risks associated with such activities and to inform appropriate countermeasures.

Methods

Ethics approval for the collection and reporting of these data was received from the Victorian Department of Justice Human Research Ethics Committee, the Royal Prince Alfred Hospital Human Research Ethics Committee, the Coronial Ethics Committee of the Coroner's Court of Western Australia, and the Queensland Office of the State Coroner.

A comprehensive search was made of the National Coronial Information System (NCIS)[9] to identify snorkelling and breath-hold diving-related cases that were reported to Australian State Coronial Services for the years 2001–2013, inclusive. These were matched with cases collected by DAN AP via the media or the diving community.

For cases prior to 2004, the author reviewed the coronial reports in conjunction with the relevant Project Stickybeak reports published in the diving medical literature.[10–12] The procedure followed for cases between 2004 and 2012 was as follows:
1. Two of the research team reviewed the police reports, witness statements and coronial reports and independently prepared a summary of each incident.
2. The author reviewed the two reports, investigated any discrepancies and prepared edited incident summaries.
3. The incident summaries, coronial and autopsy reports were independently reviewed by a research team, which variously included several diving physicians, a forensic pathologist with extensive experience in diving autopsies, a retired judge and researchers with substantial experience in diver training, data collection and accident management.
4. Annual series reports were written and published.[4,13–20]

The author solely reviewed the coronial data for cases in 2013 and extracted relevant data.

A single Poisson model provided a good fit to the deaths data across the whole study period. Analyses were performed using the Stata 15 software.[21]

Results

HISTORICAL DATA

Between 1965 and 2013 there have been a total of 337 identified deaths in snorkellers and breath-hold divers (hereinafter the combination is mainly referred to as 'snorkellers'). Figure 1 shows the annual snorkelling-related death counts with the modelled trend from the Poisson regression model. On average, snorkelling-related deaths rose by a factor of 1.55 (95% CI 1.41–1.70) each decade – so that each decade had on average 55% more deaths than the previous decade. Table 1 shows the age and gender data for this 48-year period.

Figure 2 shows the mean age at death in each year, along with the trend line fitted by the weighted least squares regression model for the years 1965 to 2013. The mean age at death rose steadily across the period to around the year 2000, when it appears to have reached a plateau.

STUDY PERIOD 2001–2013

Between 01 January 2001 and 31 December 2013, there were 175 recorded fatal incidents involving snorkellers and breath-hold divers in Australian waters. Based on the reported activity at the time of the incident, it seems reasonable to presume that 122 of the victims were predominantly 'surface snorkellers' (generally less experienced and engaged in sightseeing) and 52 were breath-hold diving (predominantly more experienced and engaged in hunting or harvesting seafood). There was insufficient information of the single remaining victim on which to make such an assessment.

Demographics

The victim demographics for this period are presented in Table 2. They were predominantly 'middle-aged' males. The age distribution for victims is shown in Figure 3. The modal class was 60–69 years and one half were aged 50 years or older. The surface snorkellers were older than the breath-hold divers with means of 53 and 39 years, respectively. The body mass indices (BMI) were available for 140 (80%) of the victims. Almost two thirds were overweight or obese, as indicated in Table 3.

Figure 1
Snorkelling and breath-hold diving fatalities in Australia, 1965–2016

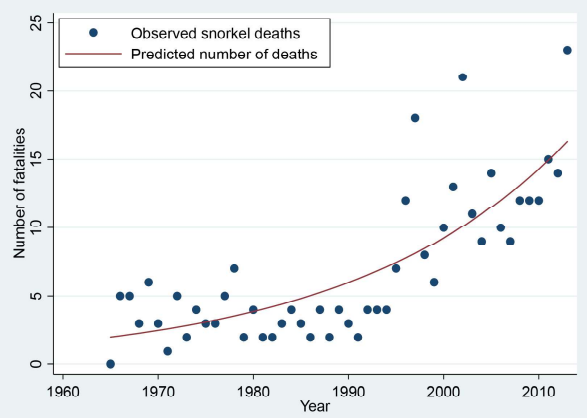


Figure 2
Mean age at death of victims of fatal snorkelling-related incidents, 1965–2013

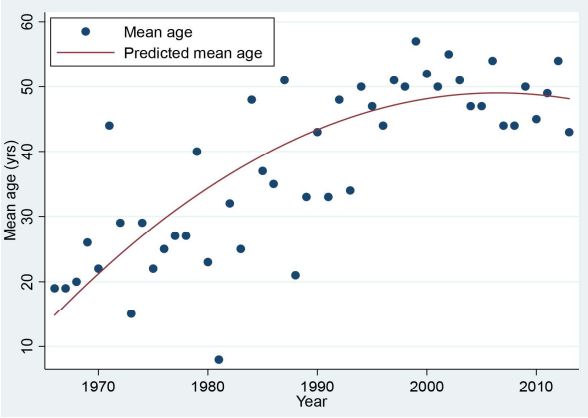


Table 2
Age measures and gender of snorkelling victims, 2001–2013

Measure	All (*n* = 175)	Male (*n* = 157)	Female (*n* = 18)
Mean (SD)	49 (18)	47.8(18.3)	59 (12.1)
Median (IQR)	51 (32, 64)	47 (31, 62)	62.5 (55, 66)
Range	15 to 85	15 to 85	25 to 70
% ≥ 50	51	45	89

Table 3
Body mass index (BMI) of victims, where known (*n* = 140). *25–29.9 kg·m^{-2}, # ≥ 30 kg·m^{-2}

BMI, kg·m^2	Mean (SD)
All	27 (5)
Male	27 (5)
Female	27 (7)
Overweight*	***n* (%)**
All	57 (41)
Male	54 (43)
Female	3 (21)
Obese#	***n* (%)**
All	33 (24)
Male	30 (24)
Female	6 (42)

Training and experience

There were only 23 reports (13%) indicating that the victim had some related training, and these included 22 with scuba training and one with apnoea diving training. Sixty-five victims (37%) were reported to have been experienced, 23 (13%) had some experience, 42 (24%) had no experience, and in 45 cases (26%) the victim's experience was unreported. The categories are based mainly on descriptive information from witness statements and subject to these limitations. Of the 128 snorkelling incidents where there was an indication of the victim's swimming ability, 24 were reported to have been weak or non-swimmers.

Location and setting

The distribution of the fatalities is shown in Table 4, the majority occurring in Queensland. Victims in Queensland were generally older than those in other locations. Sixty-five (37%) of the deaths occurred in a 'commercial' setting (that is, dives were organized by a professional entity such as a dive tour operator). This category included 47% of the surface snorkellers and four percent of the breath-hold divers. All but three of the deaths in a commercial setting were in Queensland and these comprised 60% (62/104) of the total deaths in Queensland. These mainly occurred during day trips involving snorkelling on the Great Barrier Reef (GBR).

Origin of victims

Eighty of the 104 (78%) snorkelling victims in Queensland were tourists, 73 from overseas and seven from interstate. Thirty percent of victims in Western Australia were tourists and there were relatively few deaths involving tourists elsewhere. Tourists snorkelling in Queensland had a mean age of 57 years and were older than tourists elsewhere (mean 54 years). More than 95% of the tourists appeared to have been predominantly surface snorkelling rather than breath-hold diving.

Buddy / Group situation

It is sometimes difficult to determine exactly when during an incident sequence that separation occurred. However, based on the information available, almost three quarters of the snorkelling victims were alone at the time of their incident.

Figure 3
Distribution of snorkel fatalities by age and gender (n = 175)

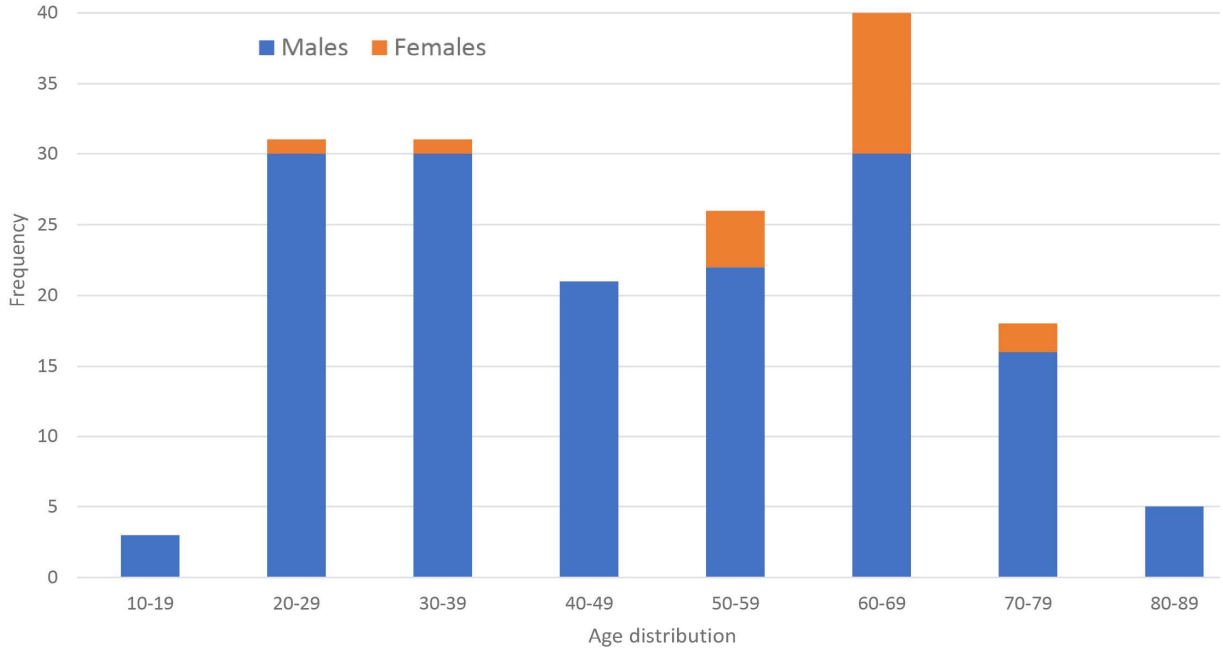


Table 4
Distribution and mean age of snorkel fatalities by State and Territory. QLD = Queensland; WA = Western Australia; NSW = New South Wales; VIC = Victoria; NT = Northern Territory; ACT = Australian Capital Territory; SA = South Australia; TAS = Tasmania

Location	*n* (%)	Age mean (SD)
QLD	104 (59)	53 (18)
WA	30 (17)	45 (17)
NSW	25 (14)	43(18)
VIC	10 (6)	34 (11)
NT	3 (2)	44 (18)
ACT	1 (1)	22
SA	1 (1)	42
TAS	1 (1)	42

Forty-seven (27%) had set out solo and 81 (46%) appeared to have separated from their buddy or buddies before the incident. Thirty-seven percent of the breath-hold divers had set out solo compared to 21% of the surface snorkellers.

Depth of incident

The vast majority (71%) of the incidents occurred at the surface. Four victims collapsed immediately after reaching the boat or land. Of the 13 incidents that were known to have occurred underwater, seven were at depths shallower than five metres, one was at 15 metres' seawater (msw) and five occurred at an unknown depth during ascent.

Weighting and floatation aids

Only 32 (18%) of the victims were known to have been wearing a weight belt and half of these were still wearing their belt when found. No specific floatation aids were used by 102 (59%) of the victims, although 14 (8%) were wearing wetsuits. Of the 17 victims who were wearing or carrying floatation aids, eight wore a life vest or jacket and seven held other floatation devices. In two cases, the type of aid was not reported.

Chain of events analysis

This chain of events analysis (CEA) is based on provisional criteria which have not been formally validated, but which have been used by the author and associates in several previous reports.[4,13,14] It utilizes similar criteria to those used (and validated) for Australian scuba diving accidents.[22]

PREDISPOSING FACTORS

Two hundred and nine predisposing factors were identified as possible or likely contributors to 173 of the fatal incidents. No factors were identified in two incidents. The main factors were health-related (n = 72) and included significant pre-existing medical conditions (n = 58), impairment by obesity (n = 4), diving whilst under the effects of drugs (n = 2). The distribution of the overall predisposing factors is shown in Table 5.

Table 5
Predisposing factors associated with 175 fatal snorkelling incidents. Some incidents involved multiple predisposing factors

72 (41%) – Health mean (SD) age 60 (15), 89% male Significant medical history: Obesity, older age	**23 (13%) Activity** mean (SD) age 30 (8), 96% male Extended apnoea (± hyperventilation) Spearfishing
53 (30%) Planning mean (SD) age 40 (16), 96% male Solo or poor buddy system Obviously unsuitable conditions	**10 (6%) Poor supervision** mean (SD) age 54 (17), 80% male Lookout failure In-water supervision failure
45 (26%) Organisational/Training/ Experience/Skills mean (SD) age 46 (18), 81% male Inexperience/poor skills Poor choice of site or conditions	**6 (3%) Equipment-related** mean (SD) age 40 (3), 100% male Weight belt problems Lack of fins and/or buoyancy aids

Table 6
The incidence of pre-existing conditions in 58 snorkellers and the associated disabling injuries in the fatal incidents. CVA = cerebrovascular accident; IHD = ischaemic heart disease; IPO = immersion pulmonary oedema; SAH = sub-arachnoid haemorrhage

Condition	*n* (%)	Disabling injury
Respiratory		
Asthma	1 (1.7)	asphyxia
Cardiac		
Arrhythmia	9 (15.5)	cardiac (8), unknown (asphyxia? IPO?, 1)
IHD (diagnosed)	22 (37.9)	cardiac (19), unknown (cardiac? asphyxia?, 3)
IHD (undiagnosed)	6 (10.3)	cardiac (5), asphyxia (1)
Valvular heart disease	3 (5.2)	cardiac (1), SAH (1), unknown (1)
Cardiomyopathy	1 (1.7)	cardiac
Other		
Drug/alcohol abuse	4 (6.9)	cardiac (3), asphyxia (1)
CVA	3 (5.2)	cardiac (3)
Diabetes	3 (5.2)	cardiac (3)
Epilepsy	3 (5.2)	asphyxia (3)
Hypertension only	3 (5.2)	cardiac (3)

Pre-existing medical conditions

Although medical histories were often unavailable, based on those available, as well as witness reports and autopsy results, pre-existing health conditions were believed to have been possible contributors in 72 (41%) of the incidents, and highly probable contributors in 58 (33%) of these. The most common condition was ischaemic heart disease (IHD), which was identified in at least 28 of the victims.

The nine pre-existing arrhythmic conditions included four atrial fibrillation, three tachycardias of unreported nature, and two other unknown arrhythmias. The predominant disabling injury in those with an identified pre-existing cardiac, cardiovascular or cerebrovascular condition or diabetes was cardiac-related (40/47 cases).

One asthmatic snorkeller died as a direct result of his asthma. Three snorkellers with known epilepsy drowned in unwitnessed circumstances. Although unproven, epilepsy may have been a contributor to some, or all, of these incidents. Table 6 shows the pre-existing conditions in 58 snorkellers where these conditions were likely to have been contributory.

Medications

The medications taken by 50 of the victims were known, although nine others were reported to have been taking unknown medications. It is likely that some others were also taking medications, but this information was not gathered. The medications will be the subject of a future report.

Planning

The main potentially contributory planning-related issue was snorkelling solo ($n = 18$) or with a very loose or absent buddy system ($n = 12$). Five victims were practicing extended breath-holding while alone in a pool. In 12 cases, the victims set out in conditions that were obviously unsuitable. Three

Table 7
Triggers associated with 175 fatal snorkelling incidents. Some incidents involved multiple triggers

98 (56%) Environment-related mean (SD) age 56 (16), 92% male conditions immersion effects marine animal and boat contact	**14 (8%) Exertion-related** mean (SD) age 60 (13), 93% male non-conditions-related carrying equipment and catches surface swims
27 (17%) Unknown mean (SD) age 46 (17), 85% male	**6 (3%) Anxiety-related** mean (SD) age 55 (16), 83% male
22 (13%) Extended apnoea mean (SD) age 28 (6), 95% male spearfishing practicing in pool or ocean	**4 (2%) Primary error** mean (SD) age 53 (15), 100% male entanglement
18 (10%) Water aspiration mean (SD) age 56 (16), 67% male primary aspiration	**3 (2%) Equipment-related** mean (SD) age 33 (18), 100% male entanglement in speargun cords tight wetsuit inappropriate snorkel

of the victims were snorkelling in an area with known boat traffic without displaying a 'Diver Below' flag and were subsequently hit by boats.

Organisational / experience / skills

The vast majority of these cases were related to the inexperience of the victims who were often first-time snorkellers. Organisational failures included poor selection or demarcation of the snorkelling site, the decision to allow snorkelling in adverse conditions, inadequate numbers or training of lookouts, and poor maintenance or absence of suitable first aid equipment. One failure included a member of staff giving poor advice about the potential seriousness and implications of an individual's medical condition.

Activity

There were 26 incidents (15%) which involved activities with a likely increased risk of a mishap. Twenty-two of these involved breath-hold divers who were pushing their apnoea limits while spearfishing, or for practice, and appeared to have drowned as a result of apnoeic hypoxia. Five of these were noted to practice pre-dive hyperventilation, although it is likely that more had done so.

Poor supervision

These incidents included four cases where there was an obvious failure of the lookouts in a commercial setting. The other cases involved poor supervision in the water by guides and in two cases spearfishing buddies who broke their agreed protocol of 'one-up-one-down', with severe consequences.

Absence of appropriate equipment or use of obviously faulty equipment

These incidents mainly involved the absence of quick-release buckles on weight belts, over-weighting, and not using fins in strong currents. There were also multiple incidents where the use of buoyancy aids may have prevented problems in weak swimmers.

TRIGGERS

One hundred and ninety-two possible or likely triggers were identified in 148 of the fatal incidents. No triggers were identified in 27 of the incidents and multiple possible triggers in 44. The frequencies and proportions of the various trigger categories are shown in Table 7.

Environmental

These triggers were often associated with adverse conditions (n = 36), namely strong currents (16), rough seas (13), or both (7). Forty-eight deaths (27%) were believed likely to have been associated with the effects of immersion; half in combination with other factors such as exertion or aspiration, and half to immersion *per se*. Almost all the latter were, by definition, associated with in cardiac disabling injuries. It was suspected that two events were likely to have been associated with epilepsy precipitated by sensory effects of immersion.

Eight incidents involved interaction with a marine creature, three of which were sharks, two Irukandji jellyfish, two crocodiles and one stingray. Four incidents involved impact with a boat and two snorkellers became entangled in lines.

Extended apnoea

These incidents involved breath-hold divers who appeared to have become unconscious as a result of extended apnoea, with or without pre-dive hyperventilation. Eleven of these were spearfishing, five were practicing extended breath-holding in the ocean, and five drowned while practicing

Table 8
Disabling agents associated with 175 fatal snorkelling incidents

78 (45%) Medical mean (SD) age 59 (15), 91% male ischaemic heart disease pre-existing arrhythmia cardiac abnormality subarachnoid haemorrhage	**20 (12%) Unconsciousness (laryngospasm?)** mean (SD) age 46 (19), 75% male
23 (13%) Environmental mean (SD) age 41 (14), 100% male adverse conditions marine animal/boat injury entrapment	**9 (5%) Buoyancy** mean (SD) age 37 (14), 100% male
21 (12%) Apnoeic hypoxia mean (SD) age 28 (5), 95% male	**24 (14%) Unknown** mean (SD) age 47 (16), 88% male

Table 9
Disabling injuries associated with 175 snorkelling fatalities. CVA = cerebrovascular accident; F = female; IPO = immersion pulmonary oedema; M = male; SAH = subarachnoid haemorrhage

Disabling injury	*n* (%)	M (%)	F (%)	Age mean (SD)	Age M mean (SD)	Age F mean (SD)
Asphyxia	70 (40)	91	9	39 (16)	37 (15)	59 (13)
Cardiac	61 (35)	90	10	61 (13)	62 (13)	59 (6)
Trauma	10 (6)	100	0	40 (11)	40 (11)	– (–)
IPO	1 (0.6)	0	100	61 (–)	– (–)	61 (–)
CVA	2 (1.2)	100	0	52 (–)	52 (–)	– (–)
SAH	1 (0.6)	100	0	52 (8)	52 (8)	– (–)
Uncertain	30 (17)	83	17	49 (20)	47 (20)	58 (19)

extended apnoea alone in a swimming pool. All but one of this cohort were relatively young males.

Aspiration

Although there were possibly many more, based on witness reports there were 18 incidents (10%) in which the primary trigger appeared to have been water aspiration, most likely through the snorkel, by inexperienced snorkellers in good conditions.

Exertion

Exertion, unrelated to adverse conditions, appeared to have been a trigger in 14 incidents (8%). Ten of these resulted in a cardiac-related disabling injury and two in cerebrovascular events.

Anxiety

Anxiety is likely a trigger in many deaths of inexperienced snorkellers. However, it was only included as a factor in this analysis when there were specific witness accounts reporting that the victim displayed signs of anxiety. There were only six such accounts (3%), all involving novices.

Equipment

Two of these incidents involved spear fishers who became entangled in their lines, another incident was triggered by difficulties associated with a tight wetsuit, and one by the victim breathing what likely became a hypercapnoeic and hypoxic gas through a hose rather than a snorkel.

Primary error

Although many incidents involved errors by snorkellers along the chain of events, these were particularly obvious in three cases, all of which involved experienced snorkellers becoming entangled in lines.

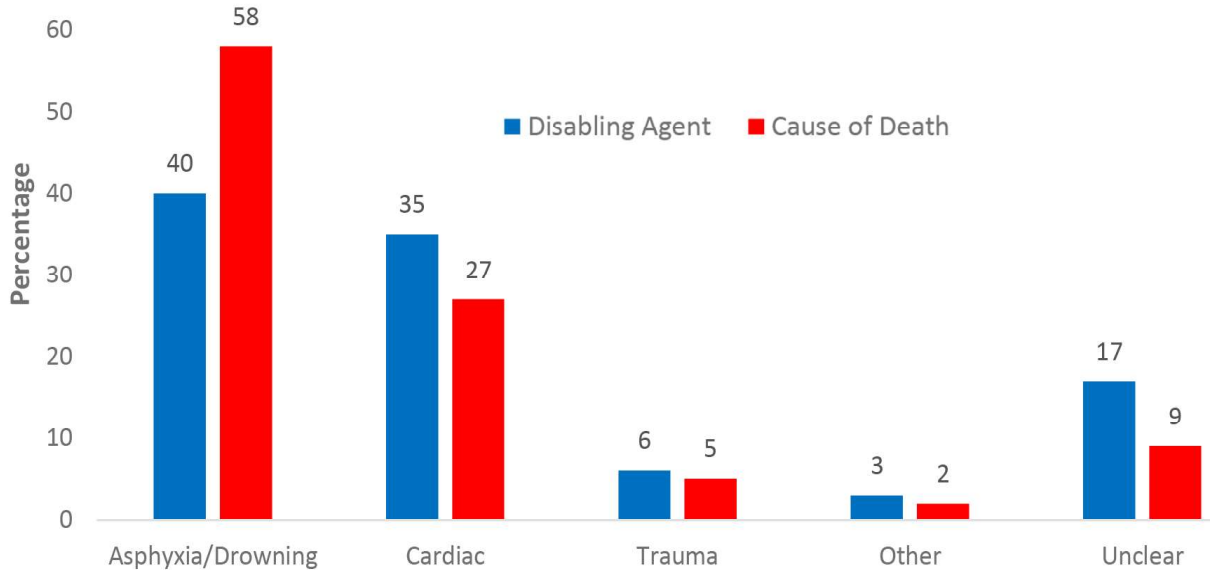
DISABLING AGENTS

There were 151 likely disabling agents identified in the 175 incidents, as shown in Table 8.

Medical

Of the 78 medical-related disabling agents, 63 appear to have been associated with pre-existing cardiac-conditions (some occult), predominantly cardiovascular/ischaemic heart disease. These included nine incidents where there

Figure 4
Comparison of disabling agents and causes of death in 175 snorkelling fatalities



was autopsy evidence of myocardial infarction. Five victims were believed to have been disabled by their pre-existing arrhythmic conditions.

Environmental

These included injuries from marine animals, which included sharks (3), crocodiles (2), irukandji-causing jellyfish (2) and a stingray. Six snorkellers were disabled by adverse sea conditions and three by contact with a boat.

Apnoeic hypoxia

The disabling agent in another 21 deaths was likely to have been a hypoxic blackout before, during or immediately after ascent as a result of extended apnoea.

Loss of consciousness post aspiration

Loss of consciousness secondary to water aspiration is likely to be a relatively common disabling agent in snorkelling accidents. There were 12 incidents identified, all involving inexperienced snorkellers, where there appeared to be no other likely extenuating factors and it is probable that the victim aspirated water (generally through the snorkel) in calm conditions and became unconscious, possibly as a result of laryngospasm. The remainder appear involve water aspiration secondary to some triggers, which in most cases involved challenging sea conditions for inexperienced snorkellers.

Buoyancy

Five of the victims were poor swimmers and two of these were wearing street clothes without fins. In three cases, the victims carried too much weight on their weight belts and were disabled as a result, one subsequent to becoming entangled in a line.

DISABLING INJURIES

The predominant disabling injuries identified were asphyxia (40%), cardiac causes (35%), although another 15 incidents (9%) may have involved cardiac-related disabling injuries. The relative occurrence is shown in Table 9. At least 45% of the snorkelling-related deaths in Queensland were cardiac-related, compared with 30% in Western Australia and 20% in New South Wales. There were no deaths identified as cardiac-related in the other States or Territories. There was only one death attributed to immersion pulmonary odema (IPO). However, due to the difficulty of distinguishing IPO from drowning at autopsy, it is possible that there were others.

A cardiac disabling injury was most often associated with exertion as at least one of the triggers [OR 5.79 (2.73, 12.30), $P < 0.0001$]. There were no other significant associations.

CAUSES OF DEATH (COD)

The predominant causes of death identified were drowning (58%), cardiac (27%) and trauma (8%). Figure 4 compares the likely disabling agents as identified by COE analysis with

the causes of death reported by the pathologists. Drowning has been the default finding in the absence of other obvious causes. The difference between the 58% drowning as COD and 40% asphyxia as disabling injury may reflect cases where drowning was secondary to a medical condition, such as a cardiac arrhythmia of which there is no direct evidence at autopsy.

Discussion

The number of snorkelling-related fatalities in Australian waters increased by approximately 50% for each decade from 1965 to 2013, likely as a result of increased participation, particularly of older individuals. One hundred and seventy-five such deaths occurred between 01 January 2001 to 31 December 2013. Most of the victims were middle-aged males, many of who were international tourists snorkelling in Queensland. Asphyxia was likely the disabling injury in 40% of these incidents, and another third of the victims appear to have been disabled by a cardiac-related event. It is important to carefully analyze these incidents in order to develop and refine appropriate countermeasures.

Demographics and characteristics

The age of the victims has increased over time, reaching a mean of 49 years during the study period, with half of these being at least 50 years old. The proportion of female victims also increased, although still over 90% of deaths were in males.

Sixty-five percent of the victims were overweight or obese. There is an association between the presence of significant health conditions and being overweight or obese,[23–26] as well as an association between obesity and sudden cardiac death.[27,28] Of particular relevance, the likelihood of a cardiac event may be increased in the context of immersion and this may partly explain the increasing incidence of cardiac-related death associated with aquatic activities.[29–31]

It is unsurprising that the majority of the victims were in Queensland and that these were generally older than in other locations. Most were international tourists and inexperienced snorkellers, who had likely included snorkelling on the GBR on their 'bucket list'. Diving-related tourism is an important income source for Queensland and there is a plethora of commercial snorkelling operations catering to the vast number of participants. These operators are required to comply with a regulated code of practice (COP)[32] in an attempt to minimize the associated morbidity and mortality, and to avoid adverse publicity associated with such deaths. Although codes of practice have been created for Victoria[33] and WA,[34] these are voluntary, weaker, likely unknown to many operators and are often not followed. Many incidents in places other than northern Queensland involved locals, with some or considerable snorkelling experience. Increased tourist and snorkelling activity along the Kimberley Coast likely accounts for the rising number of incidents in Western Australia, most involving non-locals.

Until the relatively recent introduction of formal training and certification in apnoea diving, very few snorkellers were trained, other than when undertaking scuba diving certification. Coronial reports on snorkelling fatalities rarely provide an accurate depiction of the level of experience of the victims. The inclusion of such information would be valuable in better targeting appropriate countermeasures, such as increased skills training, orientation and supervision.

Similarly, swimming ability was often not recorded. At least 15% of victims were known to be weak or non-swimmers but the actual proportion is likely to have been substantially higher. However, even strong swimmers may have difficulty snorkelling unless they have enough opportunity to learn the required skills. A suitable floatation device can help the tired, weak or non-swimmer to stay afloat and should be encouraged. However, participants are often reluctant to use these for various reasons. A lifejacket, vest or wetsuit usually needs to be well-fitted in order to be effective. The use of well-fitting fins is strongly recommended, especially in a strong current.

Health-related issues

The CEA highlights the importance of the addition of the link for predisposing factors, with the identification of more than 200 factors that were present prior to the excursion and which likely, or possibly, contributed to these deaths. Human factors may be influential throughout much of the accident chain. These include pre-existing health conditions, poor fitness, lack of experience, organisational shortfalls and poor planning or supervision. In addition, inattention, carelessness, inappropriate attitude, poor decision-making and inappropriate actions, whether prior to or during an incident, can all influence the chain of events and outcome.

Over 40% of the predisposing factors identified were health-related, unsurprising considering the mature age of much of the snorkelling cohort, particularly the surface snorkellers. Many had pre-existing medical conditions, often cardiac-related, whether diagnosed and treated, or occult. Based on witness reports and evidence of cardiac disease or abnormality at autopsy, many of the deaths thought to have been cardiac-related have been attributed to arrhythmias.[4,13–20] However, in the absence of a definitive post-mortem test and a lack of cardiac monitoring at the time of the incident, this remains speculative and warrants further investigation. While the physiological effects of immersion are well understood in the healthy individual, few data are available on immersed exercise in the more elderly who, in addition to often having underlying cardiovascular pathology and limited exercise capacity, may well be on medication that may modify their ability to deal with the physiological challenges involved.

It is important for commercial snorkel operators to explain the risks that certain medical conditions can pose while snorkelling, albeit avoiding offering medical advice unless medically qualified. It is also necessary for participants to truthfully declare such conditions so that suitable risk management measures can be enacted. This health message should also be relayed to individuals through clubs and media, to raise awareness as the opportunity arises.

Poor planning

Planning-related issues also played a large part in many of the incidents, the major one being the lack of an effective buddy system. As with scuba diving, the close proximity of a vigilant buddy can be lifesaving in the event of a mishap. Even if an inexperienced buddy is unable to perform a rescue, they may be able to alert others and so reduce the time to rescue. The fact that three quarters of these victims were alone at the time of the incident highlights the on-going need to reinforce this message, and for snorkellers to act accordingly. This should be an integral part of the preparation and briefing in a commercial setting.

The breath-hold divers were more likely to set out alone and in an unsupervised setting. Even highly experienced breath-hold divers can benefit from close supervision and the one-up-one-down protocol should be encouraged and followed.

Prompt identification of a distressed or unconscious snorkeller, together with rapid rescue will maximise the chances of survival. However, it is common for there to be substantial delays in recognition as it can sometimes be difficult to determine whether a motionless snorkeller is unconscious. This is particularly a problem with a large group of snorkellers, such as in a commercial setting. It is obvious that ratios should be minimised to increase safety, although commercial imperatives often prevail. Professional lookouts should be well-trained in scanning techniques. They should have a low tolerance to investigate if an individual is in distress. In addition, suitable rescue techniques need to be identified and practiced ensuring that they can be done swiftly and effectively when needed. First aid-related equipment (e.g., automated external defibrillator and suitable oxygen unit) needs to be readily accessible and operational, with appropriately trained staff available.

Experience, skills and conditions

As indicated earlier, most of the surface snorkelling victims were inexperienced and often first-time snorkellers. Frequently, such individuals are given only a very basic briefing and orientation. Where possible, this should be extended until the participants can demonstrate reasonable competence in the use of the mask, snorkel and fins. The level of supervision needs to be adjusted to match their skills and apparent health and fitness. The relevant COP in Queensland was recently adjusted to encourage this.[32]

On the other hand, in this series as indeed in earlier reports,[7,8] there was a significant cohort of, mainly very experienced, breath-hold divers who appear to have succumbed to apnoeic hypoxia. Some of these were reported to have practiced pre-dive hyperventilation. However, this information is often not included in witness statements and police investigators are encouraged to specifically probe this to better inform the extent of the problem. Many breath-hold divers believe that they cannot blackout without hyperventilation, but this is untrue. Due care must be taken with extended apnoea and close supervision is always prudent, although often not practiced.

It is always important to carefully consider prevailing and predicted conditions before entering the water. Conditions must be matched with each individual's skills and experience.

Boats and marine animals

Four of the deaths involved individuals who were struck by boats while snorkelling. It is always prudent to display a Diver Below flag, especially in areas frequented by boats.

Two of the three shark attack victims and one of those attacked by a crocodile were spearfishing at the time of the attack, an activity associated with an increased risk.[35] Spear fishers are well-advised to select a dive site which is not known to be frequented by large sharks, and to keep their catch well away from them to reduce the likelihood of such an incident. The wearing of protective clothing, such as a stinger suit, will greatly reduce the likelihood of an Irukandji sting.

Limitations

As with any uncontrolled case series, the collection and analysis of the fatality data are subject to inevitable limitations and uncertainties associated with the investigations. These include:

- Incomplete case data: Deaths were sometimes unwitnessed and, therefore, potentially important observational information was missing. Witness reports varied in their likely reliability. Police reports varied in their content, often related to the expertise of the investigators. This may lead to incomplete or inaccurate chain of events analyses.
- Autopsy reports: These can sometimes be unreliable as a result of the inability to detect direct evidence of cardiac arrhythmias; among other factors.
- Even with the use of a template, classification of cases into a sequence of five events using chain of events analysis is imperfect and remains vulnerable to some subjectivity.

Conclusions

Various human factors can play a substantial role throughout

the chain of events leading to a snorkelling fatality. These include pre-existing health conditions, poor skills, inexperience, poor fitness, organisational shortfalls, poor planning or supervision, among others. Each factor can predispose a diver to an incident or exacerbate a problem once adverse circumstances develop.

Chronic health conditions, such as ischaemic heart disease and cardiac arrhythmias, likely played a major role in up to 40% of these deaths, with one third attributed to a cardiac disabling injury. The interplay of immersion, exertion, anxiety, aspiration and temperature can precipitate an arrhythmia or a coronary event in a susceptible individual, which, in the water will often be fatal. It is, therefore, increasingly important to educate the community, doctors and dive industry professionals about the very real potential problems associated with the interaction between certain health-related conditions, especially cardiovascular conditions, and snorkelling.

Close supervision is strongly recommended for inexperienced snorkellers due to their likely poor skills, as well as for experienced breath-hold divers due to the potential for apnoeic hypoxia. Conditions should be matched with each participant's skills and experience. The use of a diver below flag and careful site selection can reduce the likelihood of injury from a boat, or adverse interaction with a marine predator.

References

1 Marx RF. They dared the deep – A history of diving. London: Pelham Books; 1968.
2 Surf Life Saving Australia. National coastal safety report 2018. Sydney: SLSA; 2018.
3 Tourism Research Australia. Queensland scuba diving and snorkelling report – visitor activities and characteristics [internal report only]. Queensland Government; 2007.
4 Lippmann J, Lawrence C, Fock A, Jamieson S. Provisional report on diving-related fatalities in Australian waters 2012. Diving Hyperb Med. 2018;48:141–67. doi: 10.28920/dhm48.3.141-167. PMID: 30199888. PMCID: PMC6205854.
5 Walker D. "Stickybeak" Provisional Report on Diving Deaths in 1972. SPUMS Newsletter. 1972;2(4):37–42.
6 Divers Alert Network Asia-Pacific. Diving-related fatality database and cumulative register [data only available to authorized internal investigators]. Available from: http://www.adsf.org.au. [cited 2019 February 21].
7 Edmonds CW, Walker DG. Snorkelling deaths in Australia, 1987-1996. Med J Aust. 1999;171:591–4. PMID: 10721339.
8 Lippmann JM, Pearn JH. Snorkelling-related deaths in Australia, 1994–2006. Med J Aust. 2012;197:230–2. doi: 10.5694/mja11.10988. PMID: 22900874.
9 National Coronial Information System (NCIS) [Internet]. Administered by the Victorian Department of Justice and Regulation. Available from: http://www.ncis.org.au. [cited 2018 February 25].
10 Walker D, Lippmann J. Provisional report on diving-related fatalities in Australian waters 2003. Diving Hyperb Med. 2009;39:4–19. PMID: 22753163.
11 Walker D. Provisional report on diving-related fatalities in Australian waters 2002. Diving Hyperb Med. 2008;38:8–28. PMID: 22692656.
12 Walker D. Provisional report on diving-related fatalities in Australian waters 2001. Diving Hyperb Med. 2006;36:122–38.
13 Lippmann J, Lawrence C, Fock A, Jamieson S, Harris R. Provisional report on diving-related fatalities in Australian waters 2011. Diving Hyperb Med. 2016;46:207–40. PMID: 27966202.
14 Lippmann J, Lawrence C, Fock A, Wodak T, Jamieson S, Harris R, et al. Provisional report on diving-related fatalities in Australian waters 2010. Diving Hyperb Med. 2015;45:154–75. PMID: 26415067.
15 Lippmann J, Lawrence C, Fock A, Wodak T, Jamieson S. Provisional report on diving-related fatalities in Australian waters 2009. Diving Hyperb Med. 2013;43:194–217. PMID: 24510326.
16 Lippmann J, Walker D, Lawrence C, Fock A, Wodak T, Harris R, et al. Provisional report on diving-related fatalities in Australian waters 2008. Diving Hyperb Med. 2013;43:16–34. PMID: 23508659.
17 Lippmann J, Walker D, Lawrence C, Fock A, Wodak T, Jamieson S. Provisional report on diving-related fatalities in Australian waters 2007. Diving Hyperb Med. 2012;42:151–70. PMID: 22987462.
18 Lippmann J, Walker D, Lawrence C, Fock A, Wodak T, Jamieson S. Provisional report on diving-related fatalities in Australian waters 2006. Diving Hyperb Med. 2011;41:70–84. PMID: 21848110.
19 Walker D, Lippmann J, Lawrence C, Fock A, Wodak T, Jamieson S. Provisional report on diving-related fatalities in Australian waters 2005. Diving Hyperb Med. 2010;40:131–49. PMID: 23111911.
20 Walker D, Lippmann J, Lawrence C, Huston J, Fock A. Provisional report on diving-related fatalities in Australian waters 2004. Diving Hyperb Med. 2009;39:138–61. PMID: 22753244.
21 StataCorp. Stata Statistical Software: Release 15. College Station, TX: StataCorp LLC; 2017.
22 Lippmann J, Stevenson C, McD Taylor D, Williams J, Mohebbi M. Chain of events analysis for a scuba diving fatality. Diving Hyperb Med. 2017;47:144–54. PMID: 28868594. PMCID: 6159623.
23 Cohen A, Baker J, Ardern CI. Association between body mass index, physical activity, and health-related quality of life in Canadian adults. J Aging Phys Act. 2016;24:32–8. doi: 10.1123/japa.2014-0169. PMID: 25700371.
24 Glogner S, Rosengren A, Olsson M, Gudbjörnsdottir S, Svensson AM, Lind M. The association between BMI and hospitalization for heart failure in 83,021 persons with Type 2 diabetes: a population-based study from the Swedish National Diabetes Registry. Diabetic Med. 2014;31:586–94. doi: 10.1111/dme.12340. PMID: 24147878.
25 Müller-Nordhorn J, Muckelbauer R, Englert H, Grittner U, Berger H, Sonntag F, et al. Longitudinal association between body mass index and health-related quality of life. PLoS One. 2014;9(3):e93071. doi: 10.1371/journal.pone.0093071. PMID: 24671104. PMCID: PMC3966840.
26 Kearns B, Ara R, Young T, Relton C. Association between body mass index and health-related quality of life, and the impact of self-reported long-term conditions - cross-sectional study from the South Yorkshire cohort dataset. BMC Public Health. 2013;13:1009. doi: 10.1186/1471-2458-13-1009.

PMID: 24156626. PMCID: PMC3854487.
27 Adabag S, Huxley RR, Lopez FL, Chen LY, Sotoodehnia N, Siscovick D, et al. Obesity related risk of sudden cardiac death in the atherosclerosis risk in communities study. Heart 2015;101:215–21. doi: 10.1136/heartjnl-2015-307485. PMID: 25410499. PMCID: PMC4791977.
28 Plourde B, Sarrazin JF, Nault I, Poirier P. Sudden cardiac death and obesity. Expert Rev Cardiovasc Ther. 2014;12:1099–110. doi: 10.1586/14779072.2014.952283. PMID: 25160995.
29 Bosco G, De Marzi E, Michieli P, Omar HR, Camporesi EM, Padulo J, et al. 12-lead Holter monitoring in diving and water sports: a preliminary investigation. Diving Hyperb Med. 2014;44:202–7. PMID: 25596833.
30 Shattock MJ, Tipton MJ. 'Autonomic conflict': a different way to die during cold water immersion? J Physiol. 2012;590:3219–30. doi: 10.1113/jphysiol.2012.229864. PMID: 22547634. PMCID: PMC3459038.
31 Marabotti C, Scalzini A, Cialoni D, Passera M, L'Abbate A, Bedini R. Cardiac changes induced by immersion and breath-hold diving in humans. J Appl Physiol (1985). 2009;106:293–7. doi: 10.1152/japplphysiol.00126.2008. PMID: 18467547.
32 Queensland Government. Recreational diving, recreational technical diving and snorkelling code of practice 2018. Queensland: Office of Industrial Relations – Workplace Health and Safety; 2018. [cited 2018 Feb 25]. Available from: https://www.worksafe.qld.gov.au/__data/assets/pdf_file/0004/152329/rec-diving-rec-tech-diving-snorkelling-COP-2018.pdf.
33 Dive Industry Victoria association. Code of practice for commercial providers of recreational snorkelling and scuba diving services in Victoria, Version 2. Melbourne, VIC: Dive Industry Victoria Association; 2018.
34 Diving and snorkelling codes of practice recreational diving using compressed gas and recreational snorkelling. Perth, WA: Government of Western Australia, Department of Sport and Recreation; 2003.
35 Lippmann J. Fatal shark attacks on divers in Australia, 1960-2017. Diving Hyperb Med. 2018;48:224–8. doi: 10.28920/dhm48.4.224-228. PMID: 30517954. PMCID: PMC6355314.

Acknowledgements

The author acknowledges Monash University National Centre for Coronial Information for providing access to the National Coronial Information System; State and Territory Coronial Offices; various police officers, dive operators and divers who provided information on these fatalities. Acknowledgements are also due to Dr Douglas Walker and Dr Carl Edmonds for pioneering the investigation of snorkelling fatalities in Australia, and to Dr Chris Lawrence, Dr Andrew Fock, Scott Jamieson, Tom Wodak and Dr Richard Harris for their contributions to the annual case series. Thanks also to Assoc Prof Chris Stevenson for statistical advice and to Prof David Taylor for his feedback.

Conflict of interest and funding

John Lippmann is the Founder and Chairman of DAN Asia Pacific. DAN is involved in the collection and reporting of dive accident data and provides evacuation cover and dive injury insurance to recreational divers. This study was funded by DAN Asia Pacific and the Australasian Diving Safety Foundation (ADSF).

Submitted: 14 March 2019
Accepted after revision: 21 June 2019