Medical conditions in scuba diving fatality victims in Australia, 2001 to 2013

John Lippmann[1,2], David McD Taylor[3,4]

[1] *Australasian Diving Safety Foundation, Canterbury, Victoria, Australia*
[2] *Department of Public Health and Preventive Medicine, Monash University, Victoria, Australia*
[3] *Emergency Department, Austin Hospital, Victoria, Australia*
[4] *Department of Medicine, Melbourne University, Victoria, Australia*

Corresponding author: *Dr John Lippmann, P.O. Box 478, Canterbury VIC 3126, Australia*
johnl@adsf.org

Key words
Autopsy; Cardiac; Diving deaths; Fitness to dive; Immersion; Medical conditions and problems

Abstract
(Lippmann J, Taylor D McD. Medical conditions in scuba diving fatality victims in Australia, 2001 to 2013. Diving and Hyperbaric Medicine. 2020 June 30;50(2):98–104. doi: 10.28920/dhm50.2.98-104. PMID: 32557410.)
Introduction: This study identified pre-existing medical conditions among scuba diving fatalities in Australia from 2001 to 2013, inclusive, and assessed whether these conditions likely contributed to the deaths.
Methods: The National Coronial Information System (NCIS) was searched for scuba diving-related cases during 2001–2013, inclusive. Coronial findings, witness and police reports, medical histories, and autopsy and toxicology reports were scrutinised for pre-existing medical conditions and autopsy findings. Predisposing factors, triggers, disabling agents, disabling injuries and causes of death were analysed using a validated template.
Results: There were 126 scuba diving-related fatalities identified during the study period. Forty-six (37%) divers were identified as having a significant medical condition which may have contributed to their incident. The most common condition was ischaemic heart disease (IHD) which had been diagnosed in 15 of the divers. Thirty-two (25%) deaths were attributed to cardiac disabling injuries (DI) such as ischaemic heart disease and arrhythmias, although a cardiac DI was thought likely in another six. Respiratory conditions were implicated in eight (6%) deaths, at least four associated with cerebral arterial gas embolism. At least 14 (11%) divers who had contributory pre-existing medical conditions had been cleared to dive by a medical practitioner within the year prior.
Conclusions: Chronic health-related factors played a major role in almost half of these deaths; primarily cardiac conditions such as IHD and cardiac arrhythmias. Although fitness-to-dive (FTD) assessments have limitations, the high incidence of cardiac-related deaths indicates a need for 'older' divers to be medically assessed for FTD.

Introduction

Scuba diving is conducted in an inherently hostile environment and sometimes under conditions which can be challenging to even the most healthy and fit individuals. It is generally accepted that divers should have an appropriate level of medical and physical fitness and psychological health in order to facilitate safe diving.[1] However, some of the medical conditions believed to constitute an unacceptable risk have been subject to debate over the years.

Historically, most cardiac conditions, asthma and diabetes were considered absolute contraindications to scuba diving. However, over time, various diving medical organisations have modified their positions and a substantial number of divers with these and other comorbidities are diving, largely without incident.[2–4]

Coupled with this, the sport is attracting and accepting a more widely-aged cohort of the population and long-time divers are ageing.[5,6] Associated with increasing age is a higher prevalence of co-existing disease.[7] Such conditions may have been diagnosed and medically managed. However, they may often be undiagnosed as the diver may have been asymptomatic, or symptoms may not have been reported and appropriately investigated and managed.

Diving fatality reports reflect a substantial increase in the prevalence of deaths in older divers.[8,9] This is likely the result of the combination of increased participation and increased risk imposed by age-related co-morbidities. It is, therefore, important to better understand the impact that pre-existing medical conditions may have had on diving fatalities to better inform physicians and divers about the potential risks. Given this, we aimed to identify pre-existing medical conditions in the victims of scuba diving fatalities in order to assess whether these conditions likely contributed to the deaths.

Methods

We undertook a retrospective review of scuba diving-related deaths reported to various Australian State Coronial Services

during 2001–2013, inclusive. Approval for the study was received from the Human Research Ethics Committees of the Victorian Department of Justice, the Royal Prince Alfred Hospital and the Coroner's Court of Western Australia, the Queensland Office of the State Coroner and Deakin University.

The methodology for identifying relevant cases is described in detail elsewhere.[8] In brief, it included a comprehensive key word search of the National Coronial Information System (NCIS).[10] Relevant coronial findings, witness statements, police, autopsy, toxicology and equipment reports, as well as medical histories were critically reviewed by a team which included an experienced forensic pathologist, at least two diving physicians and an experienced diving fatality researcher. Possible contributing factors to the deaths, including the impact of identified medical conditions, were discussed until consensus was reached. Annual case series were prepared and published.[11] These were used in conjunction with a validated template to identify predisposing factors to each of the deaths.[12]

Results

One hundred and twenty-six scuba diving-related fatalities were identified during the study period. Forty-six (37%) divers were identified as having a total of 62 significant medical conditions which may have contributed to their incident (Table 1).

DIAGNOSED OR UNDIAGNOSED BUT REPORTEDLY SYMPTOMATIC CARDIAC CONDITIONS

The most common condition was ischaemic heart disease (IHD) which had been diagnosed in 15 (12%) of the divers. However, another eight had not been diagnosed with cardiac disease but had experienced previous dyspnoea and/or chest pain prior to the incident. These divers had significant autopsy evidence of IHD. The disabling injury (DI) in 19 of these 23 divers appears to have been cardiac-related.

Pre-existing cardiac arrhythmic conditions were assessed as likely to have contributed to the deaths of two divers. One of these had known atrial fibrillation. The other was a 17-year-old with undiagnosed prolonged QT syndrome. Cardiac dysfunction associated with viral myocarditis was believed likely to have contributed to the rapid ascent and subsequent cerebral arterial gas embolism (CAGE) in one diver. One other diver is believed to have been disabled by an arrhythmia precipitated, in part, by mitral valve incompetence.

CARDIAC FINDINGS AT AUTOPSY

Internal post-mortem examinations were available for 123 (98%) of the divers. Overall, it was determined that 32 (25%) deaths resulted from a cardiac-related DI. Some cardiac pathology was found in 25 (20%) other cases although this was not believed to have been contributory in most of these as other more likely DI's were identified. However, in six cases, a cardiac event was believed to have been reasonably possible, although the overall evidence was not sufficiently strong to make a confident determination.

Details of cardiac findings believed to have been contributory are shown in Table 2. The data in the table relate to the 38 cases (i.e., the 32 attributed to cardiac causes and the other six thought likely).

Autopsy evidence of left ventricular hypertrophy (LVH) was found in 24 (20%) of all divers (i.e., those with either cardiac or non-cardiac DIs) for whom internal post-mortem examinations were conducted and pertinent details reported (Table 3).

RESPIRATORY CONDITIONS

Pre-existing respiratory conditions likely contributed to the deaths of eight (6%) divers. These included asthma (three divers), chronic obstructive pulmonary disease (COPD, two), pulmonary cyst (one) and pleural adhesions in two divers, one of whom had a prior pneumothorax. Five of these divers were disabled by pulmonary barotrauma (PBT) and/or CAGE.

OTHER CONDITIONS

Twelve (10%) divers were being treated for hypertension, two for non-insulin dependent diabetes mellitus (NIDDM) and two had suffered a previous stroke. At least 11 of these divers appear to have had a cardiac event while diving. Three divers had a history of seizures or epilepsy. The asphyxia-related deaths of two of these three divers were unwitnessed, and it is possible, albeit unproven, that an underwater seizure occurred.

MEDICAL ASSESSMENT

There was some information on prior medical examinations in only 38 (30%) of the cases. In these, the assessments ranged from several days to 17 months prior to the incidents. At least 14 divers who had pre-existing medical conditions that contributed to their deaths had been cleared as fit-to-dive by a medical practitioner within the year prior to their incident. Although there might have been more, only three of these 14 reports specifically indicated that the examining doctor had training in the assessment of fitness to dive (FTD) and it is likely that most of the doctors had no specific FTD training. Three of the victims had pulmonary disease (emphysema and pleural adhesions) and the remainder had cardiac conditions. One of these had undergone a cardiac stress test five months prior, with a negative result.

MEDICATIONS

The medications taken by 38 of the divers were known,

Table 1

Sixty-two pre-existing medical conditions found in 46 scuba divers and the associated disabling injuries. CAGE = cerebral arterial gas embolism; COPD = chronic obstructive pulmonary disease; CVA = cerebrovascular accident; PBT = pulmonary barotrauma; IHD = ischaemic heart disease; IPO = immersion pulmonary oedema; MV = mitral valve; NIDDM = non-insulin dependent diabetes mellitus

Condition	Cases	Disabling injuries likely associated with the condition and number of injuries
Respiratory		
Asthma	3	PBT 1, asphyxia 1, unknown (cardiac? CAGE?) 1
Pleural adhesion	2	CAGE 2
Lung cyst	1	CAGE
Emphysema	1	cardiac (also had IHD)
COPD	1	CAGE
Cardiac		
IHD (diagnosed)	15	Cardiac 12, CAGE 1, unknown (cardiac? CAGE?) 2
IHD (undiagnosed but symptomatic)	8	cardiac 7, IPO 1
Myocarditis	1	CAGE
MV incompetence	1	cardiac
Arrhythmia	2	cardiac 2
Other		
Hypertension	13	cardiac 7, asphyxia 3, CAGE 1, IPO 1, unknown (CAGE?) 1
Diabetes (NIDDM)	2	cardiac 2
IPO	1	IPO
CVA	2	cardiac 2
Aneurysm	1	asphyxia
Epilepsy/seizures	3	CAGE 1, asphyxia 2
Bipolar	1	CAGE
Ankylosing spondylitis	1	cardiac
Alcohol/drug abuse	2	cardiac 2
IgA nephritis	1	cardiac

although seven others were reported to have been taking medications, the nature of which were unknown to investigators. It is possible that some others were also taking medications, but this information was not gathered by local investigators. Non-steroidal anti-inflammatory agents ($n = 9$), ACE inhibitors ($n = 7$), SSRI agents ($n = 7$) and antiplatelet agents ($n = 6$) were the most common medications taken by the scuba victims. The specific medications and potential impact of these will be discussed in a future report.

Discussion

Pre-existing health-related factors were determined to have played a major role in many of these deaths, the main ones being cardiac-related conditions such as IHD. Many incidents were believed to have resulted from cardiac arrhythmias occurring during the dive, generally based on existing cardiac pathology and its interaction with various diving-related precipitants.

CARDIAC ARRHYTHMIAS

Arrhythmias can be precipitated by immersion *per se,* especially in cold water.[13–16] Immersion counters the effect of gravity and encourages redistribution of venous blood from the limbs into the thorax. As a result, there is a substantial increase in the cardiac pre-load and work.[16–19] In addition, myocardial work can be further increased during diving by exercise, anxiety, cold-induced vasoconstriction, respiratory resistance and increased heart rate. The potential for an arrhythmia may also be increased by hyperoxia associated with diving.[20] Together these factors increase the likelihood of a cardiac-related event in a predisposed diver.[21–23]

As there is no definitive post-mortem test to confirm whether an arrhythmia has occurred, such a determination must be based on witness reports, medical history, and surrogate markers such as evidence of cardiac disease or abnormality at autopsy. Attributing a death to an arrhythmia is, therefore,

Table 2

Cardiac findings at autopsy of 38 cardiac-related scuba deaths. Multiple abnormalities (e.g., atheroma and ischaemia) were found with many. †Significant atheroma usually taken as > 75% vessel occlusion. *includes two divers with reported myocardial infarction (MI) and two with a previously diagnosed MI. #includes eight divers with reported MI and five with a previously diagnosed MI

Condition	Divers *n* (%)
Atheroma†	26 (68)
Ischaemia*	23 (61)
Cardiomegaly#	18 (47)
Left ventricular hypertrophy	14 (37)
Undiagnosed cardiac symptoms	6 (16)
Aortic stenosis	1 (3)
Left ventricular bridging	1 (3)
Cardiomyopathy	1 (3)
Tunnelling coronary arteries	1 (3)

somewhat speculative and must be carefully assessed on the basis of the available evidence. Arrhythmias are commonly associated with coronary atherosclerosis.[24] A critical stenosis believed likely to result in ischaemia is often regarded as being greater than 75% narrowing of the lumen. However, a substantially smaller stenosis may be significant when associated with other potential risk factors.[25]

Left ventricular hypertrophy, generally consequent to hypertension, is a known risk factor for sudden cardiac death and an increased incidence of serious arrhythmias.[26–28] A comparative study of matched scuba diving and traffic accident victims reported that both heart mass and left ventricular wall thickness were greater in the scuba victims.[29] In this current Australian series, although the numbers are small and should be interpreted cautiously, 37% of the 38 divers who were believed likely or possibly to have died as a result of a cardiac-related disabling event were found to have LVH of varying degrees at autopsy. This is an area that merits further investigation with larger groups of divers matched with appropriate controls.

The 25% incidence of cardiac conditions as the disabling injury in this series is consistent with the 26% incidence reported for divers in the USA.[30] That at least one quarter of scuba deaths in this era are cardiac-related is a reflection of the increased participation of older divers, as reported elsewhere[31–33] and confirmed in this Australian series.

Although potentially limited by low response rates, some Australian diver surveys have indicated a prevalence of cardiovascular disease and/or abnormality in the diver respondents ranging from 9 to 16%.[5] These reports are considerably higher than the 6% prevalence reported for the general Australian community,[34] and are consistent with the higher age of the divers. This may help explain the incidence of cardiac-related deaths in divers.

Table 3

Autopsy findings of left ventricular hypertrophy (LVH) in scuba divers with either cardiac or non-cardiac disabling injuries. CDI = cardiac event as the disabling injury

	LVH CDI *n* = 38	LVH non-CDI *n* = 81	LVH combined *n* = 119
n (%)	14 (37)	10 (12)	24 (20)
Age (years) Mean (SD)	53 (11)	41 (12)	45 (13)

As reported elsewhere,[8] the prevalence of obesity in victims in this series is substantially higher than in the general community and suggests that being overweight or obese may be a risk factor for a scuba diving fatality, which is often cardiac-related. The body mass index (BMI) of scuba fatality victims in the USA has increased over the last decades.[9]

Our findings suggest the need for 'older' divers to be medically assessed for fitness-to-dive in order to identify or risk manage medical conditions associated with diving fatalities. Current diving medical screening guidelines recommend a cardiovascular review for all males at age 45 and females at age 55 years.[35] However, Divers Alert Network Asia-Pacific insurance records indicate that these guidelines are often not followed.[36]

RESPIRATORY CONDITIONS

Pre-existing respiratory conditions including pulmonary adhesions or cyst, previous pneumothorax, emphysema and COPD were, unsurprisingly, mainly associated with CAGE and/or PBT. These conditions, where known, would have rendered the individuals unfit to dive.

There is a considerable number of individuals with asthma who are diving in Australia,[2–5] and elsewhere.[37–39] Although asthma was a contributing factor in several deaths, asthmatics are not over-represented in this series. Some individuals with well-controlled asthma appear to be able to dive relatively safely, especially under appropriate diving medical guidance.[2]

IMMERSION PULMONARY OEDEMA

Three of the deaths in this series were attributed to immersion pulmonary oedema (IPO). However, it might have been a contributing factor or the disabling injury in another five incidents. There have been an increasing number of reported cases in divers, both fatal and otherwise but it is probable that IPO is substantially under-reported.[40–43]

Most of the victims with pre-existing medical conditions were aware of these conditions, although, in others, it was occult. Some divers, both with diagnosed or occult conditions, had prior symptoms which were unrecognised or ignored, sometimes shortly before the fatal dive. This

can be particularly problematic in the diving environment with its physical and psychological challenges and where immediate first aid and rapid medical intervention is rarely readily available.

Some divers with potentially contraindicated conditions have dived with relatively few adverse incidents, often doing many dives over many years.[2] However, this survivor cohort of divers may not have been representative of the victim cohort as they were typically managed medically and, given that they had taken out diving insurance, might be generally more aware of their health limitations.

FITNESS TO DIVE ASSESSMENT

Until relatively recently in Australia, diver certification agencies required diver trainees to undergo a FTD assessment prior to certification. However, this has been progressively abandoned since about 2013 and a FTD assessment is now only required in limited circumstances based on responses to a self-reported medical questionnaire.

Although widely-used and supported by some data,[44] this self-reporting system has limitations.[45] It relies on the divers or prospective divers, as well as the dive professionals overseeing them, to fully understand the questions and the potential implications of failing to declare a relevant health condition. In any event, even if a FTD dive medical assessment was required initially, there is generally no requirement for further assessments, except for some higher-level training. This means that much of the diving population have aged without having undergone a subsequent diving medical check.

There are several on-going issues with FTD assessments. Many are conducted by doctors who have no specific training or knowledge of diving medicine and, therefore, have little or no appreciation of the physiological effects and demands of diving. This can lead to a poor assessment of a candidate's suitability.[46] Only one half of a survey cohort of DAN AP members with known medical conditions had discussed their condition with a diving doctor.[2] All divers with potentially contraindicated conditions should be encouraged to consult with a diving medical specialist in conjunction with their treating doctor.

Some individuals intentionally withhold information for fear that they will be prevented from participating.[47] An honest and complete medical history needs to be provided in order to facilitate a more accurate assessment.

Even when conducted by appropriately trained doctors, FTD assessments are fallible and have some inherent limitations.[48] Relatively few tests are routinely performed and appropriate tests will not always reveal underlying problems. Fitness-to-dive examiners are faced with the difficulty of selecting which diver candidates to investigate further, and what are the most appropriate tests to conduct. Medicals for older divers should be viewed somewhat differently to those of younger prospective divers due to the increased likelihood of cardiovascular disease with age.[34] Cardiac investigations may often be considered based on medical history, apparent fitness and/or family history. Such investigations have a cost, an associated risk, and are prone to both false positive and false negative results. However, if concerned about the cost of such investigations, the diver or prospective diver should balance these against the cost of equipment, dive travel and the potential implications of failing to detect a serious condition.

As mentioned, despite having been assessed as FTD within the previous year, at least 14 divers in this series died as a consequence of their pre-existing health conditions. Well-considered guidance is available to FTD examiners and much of the experienced diving medical community readily avail themselves to medical colleagues to discuss and advise on diving medical issues[1,49]

Although most divers who undergo diving medicals are assessed to be 'low risk', a dive medical, especially one performed by a doctor with appropriate training, will sometimes determine that an individual has an unacceptable risk of a diving accident. This risk assessment is usually carefully explained to, and discussed with, the individual. However, there is anecdotal evidence that some undeterred and determined individuals resort to 'doctor shopping' to obtain a diving medical clearance. In fact, in this series, a diver with a history of significant emphysema sent a friend as a substitute for another assessment. His subsequent death was a result of a pulmonary barotrauma and CAGE while diving.

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. Witness reports varied in their likely reliability. Police and medical reports varied in their content. As many incidents were unwitnessed, some of the assertions in the reports are speculative. The diagnoses of cardiac disabling injuries were made based on available evidence, including autopsy reports, medical histories and witness reports and determined by consensus of an expert panel which included a forensic pathologist. However, in some cases, the final diagnoses may not be correct.

Many data items were not available which rendered the study data incomplete, thus limiting the conclusions that can be drawn.

Conclusions

Chronic health-related factors were determined to have played a major role in more than one third of the deaths in this series. The main factors identified were cardiac-related

conditions such as IHD and cardiac arrhythmias. At least one quarter of the deaths likely resulted from a cardiac disabling injury.

The comparatively high prevalence of obesity in the victims, as reported elsewhere, suggests that obesity may be a risk factor for a cardiac-related diving fatality, as may left ventricular hypertrophy. A variety of other conditions such as respiratory disease, diabetes, hypertension and possibly epilepsy were likely or possible contributors to these fatal incidents.

Fitness-to-dive assessments have limitations and relatively recent FTD assessments had failed to prevent some health-related deaths in this series. The high incidence of cardiac-related deaths indicates a need for 'older' divers to be medically assessed for FTD.

References

1 Mitchell SJ. Medical standards for recreational divers. In: Edmonds C, Bennett M, Lippmann J, Mitchell SJ, editors. Diving and subaquatic medicine, 5th ed. Boca Raton (FL): Taylor & Francis; 2016. p. 607–21.

2 Lippmann J, Taylor D McD, Stevenson C, Williams J, Mitchell SJ. Diving with pre-existing medical conditions. Diving Hyperb Med. 2017;47:180–90. doi: 10.28920/dhm47.3.180-190. PMID: 28868599. PMCID: PMC6159622.

3 Lippmann J, Taylor D McD, Stevenson C, Mitchell SJ. The demographics and diving behaviour of DAN Asia-Pacific members with and without pre-existing medical conditions. Diving Hyperb Med. 2016;46:200–6. PMID: 27966201.

4 Taylor DM, O'Toole KS, Ryan CM. Experienced, recreational scuba divers in Australia continue to dive despite medical contra-indications. Wilderness Environ Med. 2003;14:83–8. doi: 10.1580/1080-6032(2003)014[0083:ESDIAA]2.0.CO;2. PMID: 12353595.

5 Lippmann J, Taylor D McD, Stevenson C, Williams JW. Challenges in profiling Australian scuba divers through surveys. Diving Hyperb Med. 2018;48:23–30. doi: 10.28920/dhm48.1.23-30. PMID: 29557098. PMCID: PMC6467821.

6 Cummings B. National Diving Committee (NDC) diving incidents report 2014. Elmsmere Port, Cheshire: British Sub Aqua Club; 2014. Available from: https://www.bsac.com/document/bsac-diving-incident-report-2014/. [cited 2019 Oct 11].

7 Mozaffarian D, Benjamin EJ, Go AS, Arnett DK, Blaha MJ, Cushman M, et al. Heart disease and stroke statistics – 2015 update: A report from the American Heart Association. Circulation. 2015;131(4):e29–322. doi: 10.1161/CIR.0000000000000152. PMID: 25520374.

8 Lippmann J, Taylor D McD, Stevenson C. Scuba diver fatalities in Australia, 2001 to 2013 – diver demographics and characteristics. Diving Hyperb Med. 2020;50(2):105–114. doi: 10.28920/dhm50.2.105-114. PMID: 32557411.

9 Buzzacott P, editor. DAN annual diving report 2017 edition: A report on 2015 diving fatalities, injuries and incidents. Durham (NC): Divers Alert Network; 2016. Available from: https://www.diversalertnetwork.org/medical/report/AnnualDivingReport-2017Edition.pdf. [cited 2019 Sep 10]. PMID: 29553634

10 National Coronial Information System (NCIS) [Internet]. Administered by the Victorian Department of Justice and Regulation. Available from: http://www.ncis.org.au. [cited 2019 Aug 21].

11 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.

12 Lippmann J, Stevenson C, Taylor D McD, Williams J, Mohebbi M. Chain of events analysis for a scuba diving fatality. Diving Hyperb Med. 2017;47:144–54. doi: 10.28920/dhm47.3.144-154. PMID: 28868594. PMCID: PMC6159623.

13 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.

14 Marabotti C, Scalzini A, Menicucci D, Passera M, Bedini R, L'Abbate A. Cardiovascular changes during scuba diving; an underwater Doppler echocardiographic study. Acta Physiol (Oxf). 2013;209:62–8. doi: 10.1111/alpha.12112. PMID: 23638629.

15 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.

16 Chouchou F, Pichot V, Garet M, Barthélémy J-C, Roche F. Dominance in cardiac parasympathetic activity during real recreational SCUBA diving. Eur J Appl Physiol. 2009;106:345–52. doi: 10.1007/s00421-009-1010-0. PMID: 19277697.

17 Bennett M. Cardiac problems and sudden death. In: Edmonds C, Bennett M, Lippmann J, Mitchell SJ, editors. Diving and subaquatic medicine. 5th ed. Boca Raton (FL): Taylor & Francis; 2016. p. 449–57.

18 Gabrielsen A, Johansen LB, Norsk P. Central cardiovascular pressures during graded water immersion in humans. J Appl Physiol (1985). 1993;75:581–5. doi: 10.1152/jappl.1993.75.2.581. PMID: 8226455.

19 Norsk P. Gravitational stress and volume regulation. Clin Physiol. 1992;12:505–26. doi:10.1111/j.1475-097X.1992.tb00355.x. PMID: 1395444.

20 Eckenhoff RG, Knight DR. Cardiac arrhythmias and heart rate changes in prolonged hyperbaric air exposures. Undersea Biomed Res. 1984;11:355–67. PMID: 6085526.

21 Berenji Ardestani S, Buzzacott P, Eftedal I. The aging diver: endothelial biochemistry and its potential implications for cardiovascular health. Diving Hyperb Med. 2015;45:235–9. PMID: 26687310.

22 Bove AA. The cardiovascular system and diving risk. Undersea Hyperb Med. 2011;38:261–9. PMID: 21877555.

23 Thompson PD. The cardiovascular risks of diving. In: Vann RD, Lang MA, editors. Recreational diving fatalities. Proceedings of the Divers Alert Network 2010 April 8-10 workshop. Durham (NC): Divers Alert Network; 2011. p. 185–94.

24 Saffitz JE. The pathology of sudden cardiac death in patients with ischaemic heart disease – arrhythmology for anatomic pathologists. Cardiovasc Pathol. 2005;14:195–203. doi: 10.1016/j.carpath.2005.04.005. PMID: 16009318.

25 Dimaio D, Dimaio V. Forensic pathology, 2nd ed. (Practical aspects of criminal & forensic investigations). Boca Raton (FL): CRC Press; 2001. p. 44.

26 Shenasa M, Shenasa H. Hypertension, left ventricular

hypertrophy, and sudden cardiac death. Int J Cardiol. 2017;237:60–3. doi: 10.1016/j.ijcard.2017.03.002. PMID: 28285801.
27 Chatterjee S, Bavishi C, Sardar P, Agarwal V, Krishnamoorthy P, Grodzicki T, et al. Meta-analysis of left ventricular hypertrophy and sustained arrhythmias. Am J Cardiol. 2014;114:1049–52. doi: 10.1016/j.amjcard.2014.07.015. PMID: 25118122.
28 Tin LL, Beevers DG, Lip GYH. Hypertension, left ventricular hypertrophy, and sudden death. Curr Cardiol Rep. 2002;4:449–57. PMID: 12379162.
29 Denoble PJ, Nelson CL, Ranapurwala SI, Caruso JL. Prevalence of cardiomegaly and left ventricular hypertrophy in scuba diving and traffic accident victims. Undersea Hyperb Med. 2014;41:127–33. PMID: 24851550.
30 Denoble PJ, Caruso JL, de L Dear G, Pieper CF, Vann RD. Common causes of open-circuit recreational diving fatalities. Undersea Hyperb Med. 2008;35:393–406. PMID: 19175195.
31 Cumming B, Peddie C, Watson J. A review of the nature of diving in the United Kingdom and of diving fatalities (1998–2009). In: Vann RD, Lang MA, editors. Recreational diving fatalities. Proceedings of the Divers Alert Network 2010 April 8–10 workshop. Durham (NC): Divers Alert Network; 2011. p. 99–117.
32 Denoble PJ, Pollock NW, Vaithiyanathan P, Caruso JL, Dovenbarger JA, Vann RD. Scuba injury death rate among insured DAN members. Diving Hyperb Med. 2008;38:182–8. PMID: 22692749.
33 St Leger Dowse M, Waterman MK, Penny CEI, Smerdon GR. Does self-certification reflect the cardiac health of UK sport divers? Diving Hyperb Med. 2015;45:184–9. PMID: 26415070.
34 Australian Bureau of Statistics [Internet]. 4364.0.55.001-National Health Survey: First results 2017–18. 2019. Available from: https://www.aihw.gov.au/reports/heart-stroke-vascular-disease/cardiovascular-health-compendium/contents/how-many-australians-have-cardiovascular-disease. [cited 2019 January 13].
35 Mitchell SJ, Bove AA. Medical screening of recreational divers for cardiovascular disease: consensus discussion at the Divers Alert Network fatality workshop. Undersea Hyperb Med. 2011;38:289–96. PMID: 21877558.
36 Divers Alert Network Asia-Pacific. DAN AP membership medical conditions database and cumulative register. Available from: http://www.danap.org. (data available only to authorized internal investigators). [cited 2019 Sept 09].
37 Beckett A, Kordfick MF. Risk factors for dive injury. Res Sports Med. 2007;15:201–11. doi: 10.1080/15438620701526779. PMID: 17987508.
38 Glanville P, St Leger Dowse M, Bryson P. A longitudinal cohort study of UK divers with asthma: Diving habits and asthma health issues. SPUMS Journal. 2005;35:18–22.
39 Tetzlaff K, Muth CM. Demographics and respiratory illness prevalence of sport scuba divers. Int J Sports Med. 2005;26:607–10. doi: 10.1055/s-2004-821229. PMID: 16195996.
40 Edmonds C, Lippmann J, Bove A. Immersion pulmonary edema: An analysis of 31 cases from Oceania. Undersea Hyperb Med. 2019;46:581–601.
41 Edmonds C, Lippmann J, Fock A. Immersion pulmonary edema: Case reports from Oceania. Undersea Hyperb Med. 2019;46:581–601. PMID: 31683356.
42 Wilmshurst PT. Immersion pulmonary oedema: A cardiological perspective. Diving Hyperb Med. 2019;49:30–40. doi: 10.28920/dhm49.1.30-40. PMID: 30856665. PMCID: PMC6526048.
43 Peacher DF, Martina SD, Otteni CE, Wester TE, Potter JF, Moon RE. Immersion pulmonary edema and comorbidities: Case series and updated review. Med Sci Sports Exerc. 2015;47:1128–34. doi: 10.1249/MSS.0000000000000524. PMID: 25222821.
44 Glen S, White S, Douglas J. Medical supervision of sport diving in Scotland: Reassessing the need for routine medical examinations. Br J Sports Med. 2000;34:375–8. doi: 10.1136/bjsm.34.5.375. PMID: 11049148. PMCID: PMC1756251.
45 Meehan C, Bennett M. Medical assessment of fitness to dive – comparing a questionnaire and a medical interview-based approach. Diving Hyperb Med. 2010;40:119–24. PMID: 23111909.
46 Smart D, Lippmann J. Epilepsy, scuba diving and risk assessment. Near misses and the need for ongoing vigilance. Diving Hyperb Med. 2013;43:37–41. PMID: 23508661.
47 Lippmann J, Walker D, Lawrence CL, 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.
48 Lippmann J, Fock A, Arulanandam S. Cerebral arterial gas embolism with delayed treatment and a fatal outcome in a 14-year-old diver. Diving Hyperb Med. 2011;41:31–4. PMID: 21560983.
49 South Pacific Underwater Medicine Society (SPUMS). Guidelines on medical risk assessment for recreational diving. Melbourne (VIC): South Pacific Underwater Medicine Society; 2010. Available from: http://spums.org.au/content/spums-full-medical-0. [cited 2017 Dec 22].

Acknowledgements

The authors acknowledge 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 Chris Lawrence, Dr Andrew Fock, Scott Jamieson, Tom Wodak, Dr Douglas Walker and Dr Richard Harris for their contributions to the annual case series, and Assoc Prof Christopher Stevenson for some input.

Conflicts of interest and funding

The authors have no conflicts to declare. This study was funded by DAN AP and the ADSF.

Submitted: 19 November 2019
Accepted after revision: 18 January 2020