Original articles

A 10-year estimate of the incidence of decompression illness in a discrete group of recreational cave divers in Australia

Richard JD Harris, Geoff Frawley, Bridget C Devaney, Andrew Fock and Andrea B Jones

Abstract

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Introduction: The vast majority of freshwater cave diving in Australia occurs within the limestone caves of the Gambier karst in the south-east of South Australia. The incidence of decompression illness (DCI) in cave divers is presumed to be higher than open-water recreational divers because of the greater depths involved, but has not previously been reported. Our aim was to determine the incidence of DCI in cave divers, the patterns of diving and the outcome of hyperbaric treatment.

Methods: This was a retrospective cohort study of cave divers with DCI presenting to the Royal Adelaide Hospital or The Alfred Hospital over a 10-year period between 2002 and 2012. We reviewed case notes of cave divers who were treated for DCI after diving in the Mt Gambier karst. As there are no records of the number of dives performed during the study period we generated a denominator for the incidence of DCI by extrapolating available data and making a number of assumptions about the number of dives per dive permit issued.

Results: Sixteen patients were treated for DCI during the study period. The precipitating dive was a single deep decompression dive in seven cases, multiday repetitive dive sequences in eight and a non-decompression dive in one. Three of the 16 cases of DCI involved dives in excess of 90 metres' fresh water (mfw) using trimix. As the total estimated number of dives in the study period was approximately 57,000 the incidence of DCI in Australian cave divers was estimated to be 2.8:10,000 (0.028%). It is possible that the overall incidence of DCI is as high as 0.05%, and even higher when dives to depths greater than 90 mfw are involved.

Conclusions: The estimated incidence of DCS in this series is lower than expected but consistent with other series describing DCI in cold-water recreational diving.

Key words

Decompression illness; decompression sickness; cave diving; technical diving; first aid; epidemiology; clinical audit

Introduction

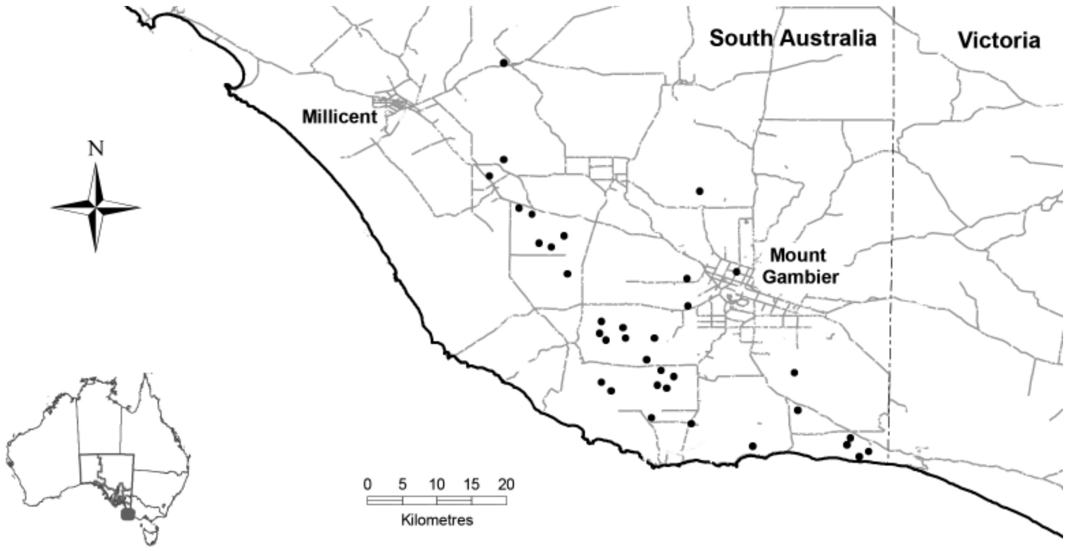
Decompression illness (DCI) describes a range of symptoms caused by bubbles in blood or tissue during or after a reduction in ambient pressure. It encompasses two pathophysiological syndromes, namely arterial gas embolism (AGE) and the more common decompression sickness (DCS). Cave diving involves entering a flooded, overhead environment and is highly equipment and technique intensive. Technical diving can be defined as using equipment and techniques to execute deeper or longer dives than recreational divers,[1] and such techniques are often used by cave divers.

Accurate incidence data for DCI in recreational divers is difficult to obtain, primarily because of the problems involved in establishing the number of participants in the activity (the denominator). It has been estimated at 0.96 per 10,000 dives (0.01%) in a cold-water recreational diving population.[2] The incidence of DCI in technical divers has been described in a number of small series but the incidence in cave divers has not been reported previously. One technical cave diving project in a deep Mount Gambier sinkhole described a DCS probability with a 95% confidence interval of 10–340/10,000 dives (0.1–3.4%).[3]

The vast majority of freshwater cave diving in Australia occurs within the confines of the Gambier karst in the south-east of South Australia (SA). The area contains many hundreds of named limestone features, many of which are a mecca for cave divers from around the country and overseas (Figure 1). Access to the diveable caves is for the most part managed by a single organization; the Cave Divers Association of Australia (CDAA). The diving is highly regulated but there are still several sources of information regarding the number of dives performed per annum. This kind of denominator for dive accident analysis is uncommon in recreational diving data. A discrete population of cave divers who perform multiple similar dives in a limited number of sites offers a unique opportunity to gain insight into the patterns and incidence of DCI in these types of dives.

Mt Gambier lies halfway between the capital cities Melbourne, Victoria, and Adelaide, SA, and the majority of CDAA members come from one of these two states. Divers who recognize that they may be suffering from DCI are likely to either self-treat (especially in mild or resolving forms) or be transferred to one of the two hospital-based recompression chambers in Melbourne and Adelaide. If a diver presents to the Mt Gambier Hospital (MGH), he or she

Figure 1
Sinkholes and cave diving sites in the Mt Gambier region, South Australia (courtesy Ian Lewis)



will usually be transferred to Adelaide regardless of their state of origin. Therefore, it is assumed that most clinically significant cases of DCI will be captured by examining cases treated at these two hospitals. This paper provides a descriptive analysis of the incidence of decompression illness arising in this population of divers.

Methods

Following ethics approval by the Human Research Ethics Committees of The Royal Adelaide Hospital (RAH), Adelaide, (HREC 120812) and The Alfred Hospital (AH), Melbourne, (HREC 365/13) the treatment databases from the two hospitals were examined to identify cases of DCS or CAGE presenting as a result of dives performed in the caves or sinkholes of the Mt Gambier karst. All cases treated at either hospital between 01 June 2002 and 31 May 2012 were identified and the case notes reviewed. Demographic data of the diver, dive profiles, exact location, dive gas and equipment configuration, presenting complaint, pre-hospital treatment, time to recompression, recompression treatment and outcome were recorded. The total numbers of cases in the ten-year period were used to form the numerator for the overall incidence of DCI.

There is no central database that accurately records the number of dives performed in the Mt Gambier cave system. However, diving in this area is highly regulated and requires daily diving permits or landowner permission. Therefore, the denominator was derived from available data recording permits issued and estimates of dives per permit. Where records were incomplete, but the frequency of permit provision was consistent, extrapolation of the available data was used to estimate the permit data for the missing time frame. Any data that were available from 2001 to 2013 (18 months either side of the study period) was used to give a 10-year figure. We gained information on the number of permits issued during the study period from a number of sources.

The CDAA currently has diving access to 24 sites in this region.[4] Through a cooperative relationship with the various landowners, the CDAA controls access and ensures divers have completed approved cave diving training. Forestry South Australia (FSA) issues permits for seven sites and maintains accurate records of permits, whilst the Lady Nelson Visitor Centre releases the access keys for four of the FSA caves. The Department of Environment, Water and Natural Resources (DEWNR) issues permits for several other caves. Eleven caves are on private property or are owned by councils and usage data for these were inconsistent. Different landowners have different access requirements. Some completely entrust the CDAA to manage dive bookings whilst others have a primary role in issuing permits. Some entrust the distribution of access keys to a third party (The Lady Nelson Visitor Centre). Finally, some sites are essentially ‘open’, requiring only a knock on the farmers’ doors. As a consequence of these disparate arrangements, no single data source exists to estimate the number of dives performed within the 10-year study period.

A number of assumptions were made to extrapolate the number of dives from the number of permits issued. This was based on the extensive cave diving experience of two of the authors (RH, AF) at these sites. Diving at sites controlled by FSA requires a permit and each diver is listed on the permit so a record of ‘user days’ is kept. For example, two divers on the permit for Forestry sites for three days will be recorded as six user days. It was assumed that six dives were performed in this time; however, it is possible that fewer dives occurred (divers not attending, apathy, illness,

Table 1
Dive site depths, (metres' fresh water, mfw) number of dives per dive site (if more than one reporting source for a site, the total shown is the mean), total estimated dives for study period (see text for explanation of how estimates were obtained) and incidents of decompression illness (DCI); DCI was attributed to a site if symptoms appeared during or after a dive in that site, regardless of previous or subsequent dive sites; in two cases, the dive site was not recorded, however, one was a sinkhole dive to 36 mfw, the other a 40 mfw training dive; *Estimated from four dives per weekend; †Estimated from six dives per weekend; ‡Total is sum of CDAA dives and ASF dives

Sites	Depth (mfw)	FSA	CDAA	Lady Nelson	ASF	DENWR	Total dives	DCI
Deep caverns/sinkholes								
Ela Elap	50						2,080*	
Gouldens Hole	26					6,078	6,078	
Hells Hole	26	350	572	201			374	
Kilsby's Sinkhole	64		6,791				6,791	7
Little Blue Lake	40						3,120†	1
One Tree	50						3,120†	1
Piccaninnie Ponds	110					5,330	5,330	1
The Shaft	120		1,563		116		1,679‡	2
The Sisters	20					400	400	
Caves								
Allendale Sinkhole	27			1,521			1,521	
Baker's Cave	32			18			18	
Mud Hole	18	7,346	3,215				5,280	
Advanced caves								
Iddlebiddy	18	1,126	709	660			832	
Nettlebed	28	855	760	573			729	
Stinging Nettle Cave	35	778	938	400			705	
Tank Cave	18		4,290				4,290	1
The Pines	40	17,654	11,396				14,525	1
Three Sisters Cave	35			27			27	
Unknown site								2
Total							**56,899**	**16**

time constraints) or more dives occurred (divers often perform two or more dives in a day). Some caves readily lend themselves to more than one dive in a day, whereas others would usually be the subject of a single dive due to their small size and tendency for silt disturbance and poor visibility. For some sites controlled by the DEWNR, only one dive per permit is allowed (a specific time slot is booked). For the other sites it is possible that more than one dive may occur per permit. As with the FSA sites, a single dive per permit has been assumed.

Collecting data for the caves on private property or owned by councils was more difficult. For each weekend permit for a site such as Tank Cave (where two to four dives would be commonplace), an assumption was made that three dives were performed. For another site, each user day has been multiplied by 1.5 to best estimate actual dives performed based on the authors' experience. An additional 116 dives performed by the Australian Speleological Federation-Cave Diving Group (ASF-CDG) Shaft Mapping Project during the study period (Payne T, personal communication, 2014) were added to the database. For three other sites, no data only estimates were available. Two sinkholes on private property and one on council land do not require any formal booking for dives, and so no records of diving are kept. An estimate (based on discussions with numerous cave divers) has been made for these sites. Some sites had maximum depths of less than 15 metres fresh water (mfw) and were included in this analysis despite the low likelihood of DCI arising from dives there. A few sites were not included as they are very shallow and seldom dived. Three large deep sinkholes on private property were only open briefly for limited diving during the study period and no data were available.

The CDAA has collected data for many sites but only intermittently. CDAA data relating to FSA sites existed for the study period but were limited to essentially the last 17 months of the 10-year period. Online bookings via the CDAA commenced in November 2010, and dive numbers up to September 2013 were used and extrapolated to a 10-year period. The data for one site, Kilsbys, were of the highest quality, over a period of 8.5 years. However, data were accurate for only or 35 months for The Shaft; and 29 months (from June 2010) for Tank Cave. The Lady Nelson Centre was able to provide seven years' data for five sites. For DEWNR sites, permit data were available for the last 30 months of the study period, and a further 18 months after this. The DEWNR total (four years) was extrapolated to 10 years.

Data from FSA probably overestimates dive numbers as some divers will book multiple sites for multiple days, but are most unlikely to complete all the dives implied by this number. The Lady Nelson numbers reflect the number of times the keys to open certain caves are borrowed and if anything this figure is likely to be more accurate or even underestimate total dive numbers. The CDAA data only commenced in June 2010, so the 10-year totals were extrapolated from a small data set. Since the data are suspected to both over- and underestimate the true values, the authors' felt it reasonable to average it where more than one source existed. These averages were summed to give the total estimated dive number for a 10-year period. For three dive sites, the numbers are truly a best guess. The booking of multiple sites on one permit introduces an error in usage rates that cannot be quantified. For example, in the study period, 7,312 user days were booked for the combination of Pines Cave and Mudhole. If each user dived both of these sites as per the booking, one could ascribe 7,312 dives to each site. However, it is the authors' experience that sometimes the secondary site (Mudhole) is booked because it is close by, but may not be dived (fatigue, time constraints, etc). As it is impossible to know exactly how many dives were performed, one diver day there has been equated with one dive.

Results

The actual and estimated numbers of dives for the caverns, sinkholes and caves in the Mount Gambier region are listed in Table 1. This amounts to a total of 56,899 dives over the 10-year study period between 2002 and 2012.

During this period, 19 divers from the Gambier karst presented to one of the two hyperbaric units for assessment (RAH 9, AH 10). Two of the RAH divers were commercial divers performing training dives in one of the sinkholes. As they were utilizing commercial diving techniques including wetsuits, surface supplied gas, surface directed decompression and DCIEM decompression tables, they were not included in this analysis as the study pertained only to recreational cave divers. One other diver presenting to the Alfred had been treated several weeks earlier at the RAH. His symptoms were attributed to the earlier episode (incomplete resolution) and no further hyperbaric treatment was given. Therefore, this second presentation was not included in the analysis. Thus, 16 divers (all male; mean age 38 +/- 5.7 years old) with DCI (all diagnosed as DCS) were treated with hyperbaric oxygen therapy (RAH 7, Alfred 9). With a total estimated number of dives in the study period of 56,899, this gives a DCI incidence of 2.8:10,000 (0.028%) for the 16 treated cases.

Dive details including gas used, depth attained and decompression plans are summarised in Table 2. The precipitating event was repetitive, multiday dive sequences in eight cases (50%), a single deep decompression dive (> 35 metres' fresh water, mfw) in five cases and a single

Table 2

Maximum depths (mfw – metres' fresh water, median and interquartile range (IQR) or range shown), risk factors, symptoms and subsequent management of 16 divers treated for decompression illness (DCI); 18:60:30 – 18 msw equivalent (284 kPa) for 60 min followed by 30-min ascent; 14:60:30 – 14 msw equivalent (243 kPa) for 60 min followed by 30-min ascent

Diving profiles and clinical data	Incidence	Comments (depth range mfw)
Maximum depth (IQR)	55 (38–72)	(n = 1) 19 (n = 10) 35–44 (n = 2) 45–60 (n = 3) > 90
Gas mixture		
Air	11	Air 39.9 (33.4–46.4)
Trimix	5	Trimix 87.2 (48.9–120)
Decompression mixture		
Air	9	
Nitrox	5	
Oxygen	2	
Predisposing factors		
Pre-dive fatigue	5	
Alcohol	5	
Post-dive exertion	5	
None	1	
Initial symptoms/signs (more than one in most divers)		
Pain	15	
Motor weakness	5	
Sensory changes	6	
Inner ear	1	
Constitutional	8	
First aid at dive site		
100% oxygen	8	
No first aid at site	8	
In-water recompression	2	
Hyperbaric treatment		
Delay to treatment (h) (IQR)	26.5 (24–48)	1 diver presented at 3 weeks
Initial treatment:		
US Navy Table 6	7	
Royal Navy Table 62	8	
Royal Navy Table 61	1	
Second treatment:		
Royal Navy Table 61	7	
18:60:30 Table	7	
14:60:30 Table	2	
Total treatments (IQR):	3 (2–4)	
Outcomes (at discharge from hospital)		
Full resolution	11	1 diver failed to return
Minor disability	4	
Total cases of treated DCI	16	

Table 3
Incidence of DCS in different dive groups and under different conditions;
AAUS – American Academy of Underwater Sciences; DAN – Divers Alert Network

Dive population	Specific cohort	Incidence per 10,000 dives	(%)	Comments
Scientific dives[15]	AAUS divers	0.324	(0.0032)	North America; 1,019,159 dives
Recreational dives	Cruise ships[13]	0.9	(0.009)	Various locations; 77,680 dives
	Cold water[2]	0.957	(0.010)	British Columbia, Canada; 146,291 dives
	Warm water[14]	1.06	(0.011)	Townsville, Australia; 677,767 dives
Project Dive Exploration[12]	All dives 1998–2004	3	(0.03)	DAN members; 80,439 dives
	Cold-water subset[6]	28	(0.28)	Scapa Flow decompression dives
	Warm-water subset[6]	2	(0.02)	
Technical dives[3]	All	10–340	(0.1–3.4)	Small series; wide 95% CIs
	Depth ≥ 90 m subset	1,330–4,550	(13.3–45.5)	

decompression dive in two cases. Three cases of DCI arose from single deep decompression dives (> 90 mfw) using trimix as the bottom gas. Eleven divers in the repetitive and multiday diving series used air as the primary breathing gas with maximum depths ranging from 19–60 mfw (mean 40.2 mfw) during single and repetitive dives. In only two of the air-diving cases did the diver appear to accelerate decompression with enriched air nitrox (EANx) or oxygen. One case involved the use of a closed-circuit rebreather, whilst all other cases presented in this paper arose from traditional open-circuit scuba.

Dives conducted during the Shaft Project and the Piccaninnie Ponds Project[5] were included in this study. The Shaft Project consisted of 116 dives which fell within the study period, (225 project dives total, with 33 dives ≥ 90 mfw). The incidence of DCI for dives deeper than 90 mfw was 6%, which is much higher than the overall incidence of DCI.[3] Similarly the incidence of DCS for dives ≥ 90 mfw during the Piccaninnie Ponds Project (consisting of 51 dives total, 15 ≥ 90 mfw) was 6.7%. This increases to 20% if two self-treated cases of mild DCS are included (Richard Harris, personal communication, 2014).

Factors considered to predispose to DCI are described in Table 2. Pain was the presenting symptom in 15 of the 16 cases and neurological symptoms were present in eleven. Of these 11 neurological presentations, weakness was noted in five and paraesthesiae in six. There was one case of inner ear DCI, which presented with vertigo and nausea. Ascent to altitude > 300 m following diving was listed as a contributor in two cases. All dives were performed in relatively cold water (11–16°C), although the almost exclusive use of dry suits in this population would be expected to prevent significant cooling. A persistent foramen ovale (PFO) was diagnosed in one diver after treatment for DCI.

Appropriate initial management of DCI with 100% oxygen was used in eight of the 16 cases. The four divers who presented to a regional health facility received oxygen and, in some cases, intravenous fluids in a timely manner. Six divers self-administered oxygen in the field and two of these performed some form of in-water recompression (IWR) before presenting to hospital.

The two hyperbaric units are 435 km (RAH) and 441 km (AH) from Mt Gambier. Even allowing for the transport times required there were significant delays to definitive treatment in this series. The mean delay to treatment for divers presenting to the RAH was 48 hours (24–96 h) following the last dive. Additional delays occurred as a result of primary triage at Mount Gambier Hospital and subsequent referral to RAH. Seven divers presented to the Alfred Hospital at a mean average time of 22 hours (12–28 h). Initial review at MGH (one diver) and Hamilton Hospital, Victoria, delayed recompression treatment by 24 h and 2.5 h respectively. Eleven divers made a full recovery and four had only minor symptoms at discharge from hospital (Table 2).

Discussion

The estimated incidence of DCS in this series (2.8:10,000 dives) is consistent with other series describing DCI in recreational divers but potentially may be higher (up to 5:10,000 dives) depending on whether or not some of our assumptions have inflated the estimated dive numbers. Nevertheless, this incidence in cave divers is lower than expected, especially allowing for the year-round cold water in the Gambier karst and the high proportion of divers likely to be performing staged decompression dives. Of all groups, cave and technical divers have been least studied. The reported incidence of DCI varies between 1:10,000 to 9.5:10,000 depending on whether the divers are involved in recreational,[2,6–8] technical,[3] scientific,[9,10] military[11] or commercial activities (Table 3).[12]

This series highlights the difficulty in accurately determining the number of dives performed in any location. The authors are optimistic that most of the significant incidents of DCI have been captured. However, it is possible that some sick divers sought treatment or follow up in other states after diving in Mt Gambier. Approximately 74% of members are from South Australia and Victoria, which does leave a significant number of interstate visitors.[4] It is also likely that some divers self-treated, ignored or had spontaneously resolving symptoms of DCI. One author (RH) is aware of several such anecdotal cases. Hence, this study almost certainly underestimates the total number of cases of DCI.

A number of areas of concern in the practice of cave diving have been highlighted by this study. The dive plans of some of the patients involved diving on air to depths of 60 mfw and a failure to plan for accelerated decompression with EANx. There are also concerns about the lack of appropriate first aid on site, use of in-water recompression and delays until definitive hyperbaric treatment. The divers in this series who developed DCI may have exacerbated development of injury in a number of ways, including provocative dives and ascent to an altitude of greater than 300 m after onset of DCI symptoms.[13] There were three divers who performed dives in excess of 90 mfw and developed DCS. A high probability of DCS (13.3–45%) was reported in a small group of technical cave divers, especially in dives performed beyond depths of 90 mfw.[3] Whilst the delay to definitive treatment could be considered unacceptably long (average 26.5 h), it does compare favourably with New Zealand recreational diver studies (mean 67 h, SD 113).[14,15] Such delays may adversely impact treatment outcomes,[16–18] although not all studies confirm this.[19]

LIMITATIONS

The greatest uncertainty lies with the accuracy of the number of dives performed. Every effort has been made to correctly determine this figure; however, the authors accept that for some sites the numbers have been extrapolated from limited data, and in other cases there is considerable variation between the different sources. The lack of precision about the number of dives is common in most studies of decompression illness. Other authors have used surrogate measures of dive numbers such as number of tank fills[2] or the results of voluntary surveys to central registries.[20,21] Both formats are likely to underestimate the total number of dives. Greater data precision is possible with scientific or military diving but this precision is unlikely to occur with cave diving until permits are provided by a single authority (such as the CDAA) and a centralised database is established. All the patients with DCI in this series were male. The fact that no female divers presented for treatment of DCI (despite representing 15% the CDAA membership)[4] might reflect different diving patterns or fewer women performing dives over 90 mfw depth.[22]

Conclusions

We found the estimated incidence of DCS in a discrete population of recreational cave divers, diving under similar conditions of depth, temperature and dive profile, to be approximately 2.8:10,000 (or possibly up to 5:10,000 dives). This appears to be well within the expected range for decompression diving in cool water, and suggests that current diving practices and training within this population are effective and appropriate.[21,23] However, in the subset of deep dives beyond 90 mfw, the DCS incidence is much higher, suggesting that current diving practices in this range need further refinement. Only a small proportion of divers self-administered oxygen as first aid and there appears to be a disjoint between diver education and practical application regarding the suggested risk factors for DCI. Despite significant delays to definitive treatment, outcomes for most divers were excellent.

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Conflict of interest

Richard Harris is the Search and Rescue Officer for the CDAA.

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Richard JD Harris[1], Geoffrey Frawley[2], Bridget C Devaney[2], Andrew Fock[2], Andrea B Jones[1]
[1] Hyperbaric Medicine Unit, The Royal Adelaide Hospital, North Terracece, Adelaide
[2] Department of Intensive Care and Hyperbaric Medicine, The Alfred Hospital, Melbourne

Address for correspondence:
Richard Harris
Hyperbaric Medicine Unit
Royal Adelaide Hospital
North Terrace
Adelaide, SA 5000
Australia
Phone: *+64-(0)8-8222-5116*
E-mail: *<drharry@me.com>*