Decompression illness in breath-hold divers: insights from an online survey

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Abstract
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Introduction: Breath-hold divers can surface with neurological symptoms consistent with nitrogen buildup in tissues or gas entry into the arterial circulation, collectively termed decompression illness (DCI). While DCI has historically been attributed to diving with compressed air, breath-hold divers have reported similar syndromes. The causes, diagnosis, and management of DCI in breath-hold divers is poorly understood.
Methods: We developed an online survey that queried breath-hold divers on the symptoms they experienced during decompression illness events and the medical management of each event.
Results: A total of 36 (31 M, 5 F) breath-hold divers filled out the survey. A majority identified as recreational freedivers, competitive freedivers, and/or spearfishers with an average age of 45 years and 18 years of breath-hold diving experience. Of those surveyed, 33 (92%) held a certification from an accredited training agency. A total of 18 (50%) reported experiencing DCI, with 21 DCI incidents reported by 13 individuals from 1999–2024. Sixteen (76%) of DCI incidents occurred during training, with an average depth of 83.4 m and average speed of 1.0 $m \cdot s^{-1}$. Thirteen (62%) percent of DCI incidents occurred while diving to depths shallower than a previous personal best. The most common symptoms were weakness, numbness, slurred speech, and fatigue. The most common treatment modalities were surface oxygen, in-water recompression, and hyperbaric oxygen therapy. Sixteen divers (76%) had partial or complete resolution of their symptoms. The top cited contributors to the DCI incidents were depth, short surface interval between dives, and pulmonary barotrauma.
Conclusions: Breath-hold divers can experience DCI even when diving within their limits. The most cited contributors to DCI were depth, short surface interval between dives, and pulmonary barotrauma. Most divers' symptoms resolved after treatment with surface oxygen, in-water recompression, and/or hyperbaric oxygen therapy.

Introduction

Breath-hold divers, commonly called freedivers, have in the past described neurological symptoms after certain dives that have been attributed to both nitrogen loading in cerebral tissue as well as gas entry into the arterial circulation.[1] This syndrome was initially titled Taravana syndrome which means "*to fall crazily*" by physicians who noticed Polynesian pearl fisherman with ataxia after repetitive dives,[2] then later attributed to cerebral decompression sickness as the knowledge of decompression-related injuries became more well-described in compressed-air divers, including scuba, surface-supplied, and saturation divers. Neurological symptoms consistent with decompression illness (DCI), which encompasses both decompression sickness as well as arterial gas embolism, have been described in the literature by commercial,[3] competitive,[4] as well as recreational breath-hold divers.[5] Risk factors attributed to the development of decompression illness from breath-hold diving include repetitive dives with short surface intervals,[3] long deep dives > 100 m,[6] and a fast rate of ascent.[7]

DCI is diagnosed clinically with frequent and thorough neurological examination and re-examination after a dive, as many symptoms can overlap with those of extreme physical effort, hypercapnia, and hypoxaemia. Common symptoms include headache, dizziness, vertigo, confusion, vision changes, focal paresthesias, generalised weakness, and speech difficulty.[8] The distribution may not follow specific vascular regions typical for ischaemic strokes, thereby DCI should still be considered when the pattern of neurological symptoms do not follow classical patterns of

cerebrovascular accidents. Non-neurological manifestations of DCI can include dermatological, musculoskeletal, pulmonary, and constitutional symptoms.[9] While DCI in freedivers is becoming more recognised in the diving medical community, treatment has largely mirrored that of DCI in scuba and commercial divers, focusing on oxygen therapy and recompression. A large challenge to treatment is that freediving often occurs in remote locations with no immediate access to medical facilities and/or hyperbaric chambers. We therefore developed a survey which sought to explore the medical management of DCI in freedivers and the outcome of various treatments.

Methods

The study was approved by the University of California San Diego Institutional Review Board. Data collection was open for seven months from June–December, 2024.

This study was designed as a retrospective study with convenience sampling by survey. The survey was developed using Qualtrics and distributed via the Divers Alert Network and University of California San Diego to social media and freediving message groups. There was no paper version. The study population included divers 18 years or older who could read English and had access to the internet. Participants were recruited with a tagline of "*Breath-Hold Divers: Have you ever experienced decompression illness? We want to hear from you! Fill out our short survey below*." Participants had to consent to both conditions on an initial consent page before accessing the survey. This survey did not have an intervention as it was retrospective. There was no comparison group, as this was an attempt to gather data on a group where DCI is not well documented. The desired outcome of the survey was to gather anonymous data on the manifestations, circumstances, and treatment surrounding suspected DCI incidents in breath-hold divers.

The survey was divided into two parts: the diver's demographic data, and the opportunity to report on DCI incidents. In the first part, each diver's age, sex, gender, past medical history, experience and training in breath-hold diving, and familiarity with decompression illness medical terminology was collected. In the second part, divers were invited (but not required) to provide information on any decompression incident they experienced, including their symptoms, treatment, and likely causes. The survey had 11 demographic questions per diver and 14 questions per incident and was estimated to take 10 minutes to complete (*Appendix 1). Descriptive statistics were used for all data points.

The survey was closed after two months of no further responses despite multiple repeated postings on social media and in messaging groups.

Results

RESPONDENTS

A total of 54 responses were recorded, of which 18 respondents did not complete the first half of the survey, which collected individual demographics. Of the complete 36 respondents, the biological sex of 31 were male. The gender identities of the respondents were 30 men, four women, one nonbinary, and one chose not to respond. Their ages ranged from 21–73 years of age, with a mean of 45.6 (standard deviation [SD] 14.6) years. Four of the respondents reported a known patent foramen ovale, two had previous strokes, and one had a previous spinal cord injury. Three of the respondents had previously had surgery on their back and/or neck and two had previously had brain surgery.

Respondents had a range of 2–45 years of experience diving, with a median of 11 (interquartile range [IQR] 23). The types of breath-hold diving they participated in included recreational freediving (33), competitive freediving (24), spearfishing (14), underwater rugby and/or hockey (5), underwater target shooting (1), underwater aquathlon (1), and fin swimming (1).

Thirty-three of the respondents (92%) held a certification from an accredited training agency. Certifying agencies included Association Internationale pour le Développement de l'Apnée (AIDA) (12), Confédération Mondiale des Activités Subaquatiques (CMAS) (12), Molchanovs (9), Scuba Schools International (SSI) (8), Freediving Instructors International (4), Professional Association of Diving Instructors (4), Apnea Academy (2), Apnea Total (2), Performance Freediving International (2), National Association of Underwater Instructors (1). Levels of certification the respondents had achieved included 10m depth (1), 20m depth (1), 30m depth (3), 40m depth (1), instructor (13), instructor trainer (9), competitor (10), safety diver (8) and judge (1). Thirty of the respondents (83%) were also certified in scuba.

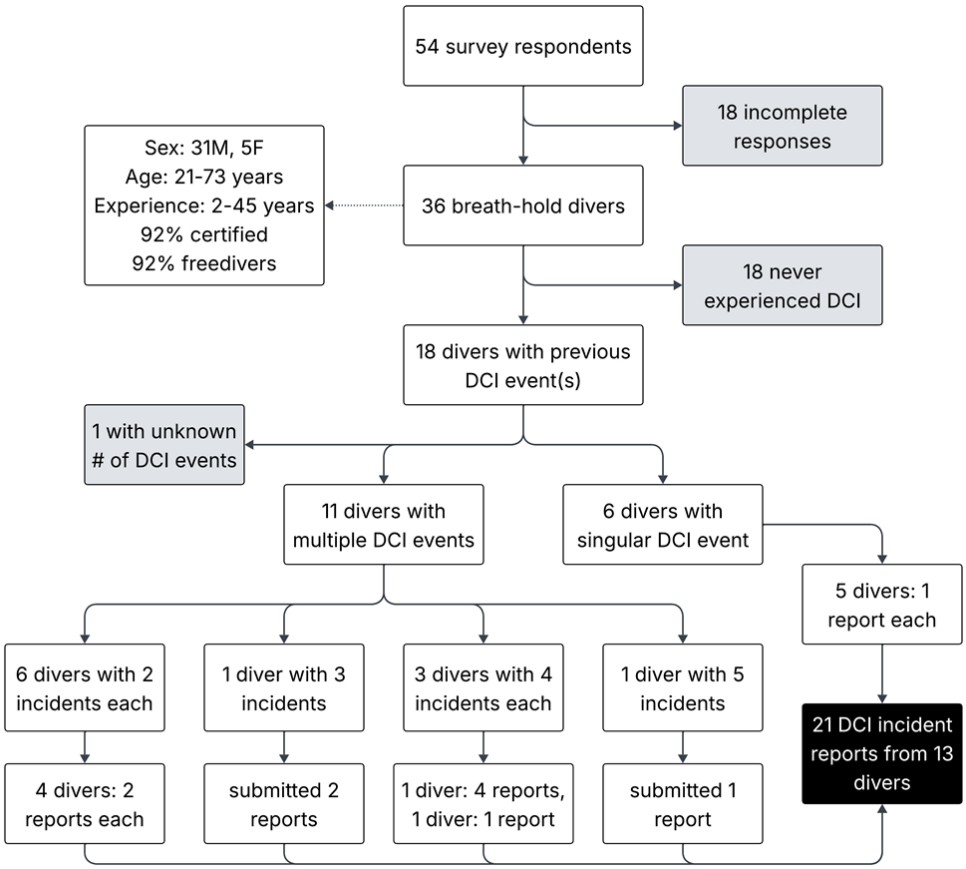
Regarding decompression terminology, respondents were familiar with the terms decompression sickness (32), arterial gas embolism (29), decompression illness (30), and Taravana Syndrome (17). Eighteen (50%) reported experiencing a decompression related event. Eleven (65%) respondents reported to have experienced more than one event (Figure 1).

DECOMPRESSION ILLNESS INCIDENTS

A total of 24 DCI incidents were reported in the survey, of which three incidents had incomplete data. The reported incidents occurred between the years of 1999–2024. The 21 complete incidents were from 13 individual divers (Table 1). The types of dives resulting in the incidents were training

***Footnote:** Supplementary Appendix 1 is available to view at https://www.dhmjournal.com/index.php/journals?id=375

Figure 1
Breakdown of survey respondents; DCI – decompression illness; F – female; M – male



(16), competition (2), recreational (2), and instructing (1). The disciplines resulting in the incidents were free immersion (FIM, 7), constant weight monofin (CWT, 4) constant weight bi-fins (CWTB, 2), scooter (2), constant weight no fins (CNF, 1), and unknown (5). The target depth of the incident dives ranged from 20–127 m (mean 83.5 m, SD 28.9 m) and the achieved depths ranged from 20–127 m (mean 83.4 m, SD 26.8 m). Thirteen (62%) of the incident dives were shallower than a previous personal best (PB); three (14%) were deeper, two (9.5%) were the same depth as a previous PB, and three (14%) were unknown. The speed of the incident dives ranged from 0.5–2.0 $m \cdot s^{-1}$ (mean 1.0 $m \cdot s^{-1}$, SD 0.4).

Fifteen (71%) of the incident dives involved pre-dive lung 'packing' (glossopharyngeal insufflation), with a range of 1–50 packs (mean 21.3, SD 11.9). On sixteen (76%) of the incident dives, divers did not perform pre-surfacing exhalation. Three (14%) of the incident dives had concurrent blackout in addition to DCI. Two of the three blackouts (66%) were underwater.

The symptoms described during the DCI incidents included constitutional, neurological, cardiopulmonary, and dermatological. Treatment modalities included cardiopulmonary resuscitation (CPR, 1), surface oxygen (14), in-water recompression (IWR, 9), and chamber-based hyperbaric oxygen treatment (HBOT, 7). Surface oxygen administration ranged from 10–90 min (mean 50, SD 26.3). IWR regimens ranged from 6–29 min at depths of 5–18.7 m; HBOT regimens ranged from 1–11 sessions (mean 4.9, SD 4.3) with various tables used (Table 2). After treatment, eight had complete resolution of symptoms, eight had partial resolution of symptoms, two had no change in symptoms, and three were unknown (Table 3).

Eleven of the incident dives were reported to the Divers Alert Network (DAN). Divers sought medical evaluation after 15 of the incident dives, and nine were admitted to the hospital for their symptoms. Medical workup included laboratory studies (7), computed tomography (6), ultrasonography (6), and magnetic resonance imaging (4). The respondents reported what they perceived as the plausible cause(s) of DCI incidents as repetitive dives with short surface interval (5), depth of the dive (5), pulmonary barotrauma (4), duration of dive (3), fast ascent (3), diving beyond their limits (2), overpacking (2), exertion at depth (2), no pre-surface exhale (2), blackout (1), dehydration (1), exhaustion (1), and competition nerves (1).

Table 1

DCI incidents and reported symptoms; AMS – altered mental status; CP – chest pain; L – left; R – right; SOB – short of breath

Diver	# Reports	Symptoms											
		Weakness	Numbness	Δ Speech	AMS	Δ Vision	Hearing	Ataxia	Fatigue	Dizzy	SOB	CP	Other
1	2	x	x						x	x	x	x	
		x	x		x				x	x	x	x	
2	1												itching to arms/legs
3	1		x										
4	2		R leg										
		legs	legs	x	x	narrowed	x	x	x	x	x	x	
5	1	x		x	x	x		x	x	x			
6	1	x											
7	1	R leg	R leg						x		x		
8	1	x											
9	4							x					headache
		L side	arms	x		blurry		x	x	x	x		
		L arm		aphasia		blurry			x		x		
		L arm		x					x	x	x		
10	2	x	face		x			x	x	x			
		R side	x	x						x			nausea/vomiting
11	2	x	x	x	x			x					
		x	x	x	x	x		x		x			
12	2		R arm								x		
		x		x	x	blurry		x					
13	1	R side		x	x				x				

Table 2
Recompression treatments reported by respondents; HBOT – hyperbaric oxygen treatment; US – United States

Recompression modality			
In-water recompression		**HBOT in a hyperbaric chamber**	
Time	**Depth**	**Protocol**	**Sessions**
5 minutes	5 m (repeat x 4)	US Navy Table 6a	1
6 minutes	5 m	US Navy Table 9	1
10 minutes	6 m	unknown	5
20 minutes	7–10 m	US Navy Table 6	5
20 minutes	15 m	US Navy Table 6a THEN US Navy Table 9	10
8 minutes 3 minutes 8 minutes 10 minutes	18.7 m THEN 15 m THEN 10 m THEN 5 m	US Navy Table 6a THEN Modified US Navy Table 5	11

Table 3
Outcomes after different treatment modalities reported by respondents; HBOT – hyperbaric oxygen treatment; IWR – in water recompression

Treatment modality			Symptom resolution
Surface oxygen	**In-water recompression**	**HBOT**	
No Treatment (1)			Unknown (1)
Surface O_2 Only (9)			Complete (3) Partial (3) Unchanged (2) Unknown (1)
	IWR Only (3)		Complete (2) Unknown (1)
Surface O_2 + IWR (1)			Complete (1)
Surface O_2		+ HBOT (2)	Partial (2)
	IWR + HBOT (3)		Complete (2) Partial (1)
Surface O_2 + IWR + HBOT (2)			Partial (2)

Discussion

This survey represents responses from a group of majority male middle-aged divers with a decade of breath-hold diving experience. Most of them were certified by a freediving organisation and two thirds of them participated in competitive freediving. Several respondents reported more than one DCI incident. Most incidents occurred during training, which may have resulted in less access to medical resources than a competition setting.

Most DCI incidents occurred during deep dives, with mean depths deeper than 80 m. Divers often attributed depth as a cause of DCI, likely due to deeper dives taking longer, thereby allowing for gas diffusion into fast tissues. It has been postulated that venous gas emboli that develop at depth may enter the arterial side through intrapulmonary arteriovenous anastomoses[10] in the absence of a patent foramen ovale (PFO), that nanobubbles can form on active hydrophobic spots within blood vessels,[11] and that profound cerebral hypotension at depth can result in low perfusion and cerebral infarct.[12]

Of the four divers who had a known PFO, three reported experiencing a DCI incident. While the survey did not specifically ask if the PFO was discovered before or after the DCI incident, it is possible that these divers only know about their PFO at the time they filled out the survey because they had an agitated saline contrast echocardiogram 'bubble study' in the aftermath of their incident. If they did discover this, it is interesting that none of the divers considered the PFO to be the cause of their DCI incident.

Multiple divers reported short surface intervals between repetitive dives as a primary cause for a DCI incident. If divers completed multiple dives with short surface intervals, it is plausible that nitrogen loading in fast tissues could result in DCI. Predictive modelling has led to a recommendation of a surface interval twice the duration of the dive,[13] although many freedivers adhere to even longer intervals beyond certain depths.[14]

A majority of divers lung-packed before the dive and did not perform a pre-surface exhale, which may increase the risk of pulmonary barotrauma from overexpansion, which can create communication between the pulmonary and arterial systems and lead to gas embolisation. While packing is not encouraged in recreational courses, it is still common practice amongst competitive breath-hold divers. In addition to the neurological symptoms expected in DCI, some divers additionally reported cardiopulmonary symptoms that could indicate concurrent pulmonary barotrauma.

Four divers reported a concurrent blackout on the incident dive. Blackouts are often attributed to hypoxia of ascent, which can also present as a loss of motor control. Many constitutional or generalised neurological symptoms reported in these incidents could be due to transient hypoxia or inert gas narcosis from the breath-hold dive. This may explain why some incidents resolved after surface (normobaric) oxygen protocols as short as 10 minutes. In DCI, normobaric oxygen should be applied as a bridge to HBOT, with a minimum of 30 minutes and average treatment time of over 2 hours.[15]

One diver reported receiving cardiopulmonary resuscitation (CPR) before other treatments. This is likely due to the underwater blackout that occurred on this incident dive, resulting in an aspiration/drowning event. It is therefore possible that the symptoms reported in this case are sequelae of the cardiopulmonary arrest and not decompression illness.

Many divers self-treated with IWR using a wide range of recompression regimens. The lack of medical oversight is likely why there was no agreement between the utilised regimens, as none follow previously published protocols meant to be administered by divers trained in decompression procedures.[16,17] We suspect that IWR was self-administered when there was delayed or no access to a hyperbaric chamber, as many training and competition sites are far from chambers. Cost may also be a factor, as oxygen may be readily available from a dive shop whereas medical treatment can be a significant expense in many locales. Many dive insurance companies do not cover competition dives, and therefore competitors may have attempted to substitute on-site IWR for otherwise costly HBOT.

Only one third of the divers received HBOT, which is the gold standard for DCI. This could be due to location and cost issues, or due to symptoms resolving with normobaric oxygen and/or IWR. It could also be due to lack of medical knowledge about DCI in breath-hold divers leading to medical facilities denying or withholding HBOT for neurological symptoms after breath-hold diving.

LIMITATIONS

The authors acknowledge that this was a retrospective survey with self-reported responses. The survey title included the phrase ‘decompression illness’, therefore only breath-hold divers with familiarity with DCI may have responded. Additionally, divers who perceived that they knew what DCI was may have responded but may have discovered in the course of filling out the survey that they had not in fact experienced DCI, thereby resulting in less than half of the original respondents actually submitting an incident report.

The respondents were athletes and may have omitted details that are relevant to medical providers in the diagnosis of decompression-related injuries. Some reported incidents that occurred years before taking the survey, and it is possible that memories of the event were modified over time or are inaccurate.

This survey did not collect information on surface intervals between previous dives and therefore cannot draw conclusions on whether a diver’s surface interval could have led to DCI. This survey did not ask about any potential adverse events as a result of medical treatments. Not all divers volunteered contact information for follow-up or clarification of their incident(s).

Conclusions

This retrospective survey sought to collect data about decompression illness in breath-hold divers from self-reported incidents. We found that breath-hold divers can experience symptoms consistent with decompression illness even after a single dive. Deep dives, short surface intervals between dives, and concurrent pulmonary barotrauma were the most cited suspected causes of DCI. Many incidents resolved after normobaric oxygen or self-administered in-water recompression, with only a third of divers receiving gold-standard hyperbaric oxygen therapy in a chamber. Less than 75% of divers sought formal medical evaluation. The IWR regimens utilized varied and did not follow any previously published IWR treatment regimens. Further research is needed to determine the best management of breath-hold diving related DCI and consensus on treatment regimens.

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