Occurrence and resolution of freediving-induced pulmonary syndrome in breath-hold divers: an online survey of lung squeeze incidents

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Abstract
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Introduction: Breath-hold divers occasionally surface with signs of fluid accumulation and/or bleeding in air-filled spaces. This constellation of symptoms, recently termed 'freediving induced pulmonary syndrome', is thought to come from immersion pulmonary oedema and/or barotrauma of descent and is colloquially termed a 'squeeze'. There is limited understanding of the causes, diagnosis, management, and return to diving recommendations after a squeeze.
Methods: We developed an online survey that queried breath-hold divers on the circumstances and management of individual squeeze events.
Results: A total of 132 (94 M, 38 F) breath-hold divers filled out the survey. Most were recreational or competitive freedivers with mean age of 37 years old and nine years of experience. Of those, 129 (98%) held a certification in freediving from an accredited training agency. A total of 103 individuals reported 140 squeeze events from 2008–2023. The average depth at which a squeeze occurred was 43 m. The top contributors to lung squeezes were described as movement at depth, contractions, and inadequate warm-up. The most common symptoms of a squeeze were cough, sputum production, and fatigue. Divers were instructed to wait an average of two months before returning to diving after a squeeze. On average, divers were able to achieve the same depth of their squeeze event three months after the incident.
Conclusions: Inadequate warm-up, contractions, and abnormal movement at depth are the most reported causes for a squeeze. Most divers do not seek medical treatment after a lung squeeze event and can return to the same depth within three months.

Introduction

Breath-hold divers occasionally surface with signs of fluid accumulation and/or bleeding in air-filled spaces. This constellation of symptoms is thought to come from barotrauma of descent and is colloquially termed a 'squeeze'.[1,2] A mask squeeze results in subconjunctival haemorrhage[3] while a middle ear squeeze may result in tympanic membrane rupture.[1] Not all squeezes result in obvious bleeding. A sinus squeeze may cause epistaxis or be limited to sinus discomfort while a laryngeal squeeze may cause haemoptysis or be limited to voice changes.[1] A squeeze in the lung may result in more subtle symptoms and frank haemoptysis may be absent.

The pathophysiology of lung squeeze is poorly understood and thought to be a combination of factors including pulmonary vascular engorgement,[4] diaphragmatic contractions,[5] equalisation, and movement at depth. The constellation of symptoms is similar to immersion pulmonary oedema experienced by compressed air divers and surface swimmers.[6] Alveolar haemorrhage and interstitial oedema can both lead to impaired ventilation, resulting in respiratory discomfort, difficulty, or distress. It was recently suggested to encompass these symptoms under 'freediving induced pulmonary syndrome' (FIPS) as an umbrella term.[7] Auscultation, pulse oximetry,[8] and point-of-care ultrasound devices are the most commonly used tools to diagnose lung squeeze in a field setting.[2] In-hospital radiographs,[9] computed tomography,[10] and bronchoscopy can help aid in the diagnosis.[11] Squeezes are often self-limited, and therefore divers may not present for medical evaluation.

Since many competitive events have limitations on participation with recent dive injuries, mild symptoms may be underreported. As such, there are no universal clinical guidelines for returning to diving after a squeeze.

At present, this time frame is dictated by coaches, fellow divers, competition judges, medics, or health practitioners who may not be well-versed in freediving pathophysiology. This survey sought to explore the incidence of lung squeezes, medical management of squeeze symptoms, and return to diving after a squeeze.

Methods

Ethical approval was granted by the Institutional Review Board of Divers Alert Network (DAN) under IRB 033-23; data collection was open for eight weeks from 28 August to 25 October 2023.

An online survey was developed using REDCap and distributed to breath-hold divers through DAN's social media outlets (Facebook, Instagram, and Twitter). The study included divers 18 years and older. Participants were presented with a participant information page and this required them to indicate consent before progressing to the survey. Each diver's demographic information, training and experience in different breath-hold diving disciplines was collected, as well as symptoms of individual lung squeeze incidents, and medical care received if applicable. Divers were also asked to share their thoughts on what contributed to their lung squeeze incident.

Data were analysed using GraphPad Prism(R) 10. Descriptive statistics were reported for demographic information and dive experience calculating average with standard deviation or median with interquartile range.

All data were downloaded from REDCap to a database on a secure server at Divers Alert Network and identifying information (voluntarily provided contact information) was removed before datasets were analysed.

Results

RESPONDENTS

There were 164 submissions received, of which 27 were incomplete. Of the 137 full submissions, five datasets were identified as duplicates, leaving 132 datasets for analysis that were de-identified. Of the participants, 94 (71.2%) identified as male. Their ages ranged from 20–74, with a mean (standard deviation [SD]) age of 37 (SD 9) years and a median (interquartile range [IQR]) of 35 (IQR 31–42) years. Their experience ranged from under one to 45 years, with a mean of nine (SD 8) years and a median of 6.5 (IQR 3–11) years. They participated in the following breath-hold diving activities: recreational freediving (122), competitive freediving (89), spearfishing (36), underwater hockey (4), aquathlon (3), and underwater target shooting (2). All reported various training frequencies, ranging from daily (32, 24%) to weekly (60, 45%) to monthly (8, 6%) to seasonally (32, 24%).

Of the respondents, 129 (98%) were certified by one or more organisations. Certifying organisations included the Association Internationale pour le Développement de l'Apnée (AIDA) (68), Molchanovs (47), Scuba Schools International (SSI) (27), Confederation Mondiale des Activites Subaquatiques (CMAS) (21), Professional Association of Diving Instructors (PADI) (13), Apnea Academy (eight), and the following with five or less survey participants certified: Performance Freediving International, Apnea Total, Freediving Instructors International, National Association of Underwater Instructors, Rebreather Association of International Divers, Fédération Française d'Études et de Sports Sous-Marins, Apnea College, Apnea International, Professional Scuba Schools, and Pure Apnea. Levels of certification distinguished between pool (47), 10 m depth (18), 20 m depth (20), 30 m depth (38), 40+ m depth (61), instructor (82), instructor trainer (9), competitor (46), and safety diver (28). Of the respondents, 94 (71%) also reported being certified in self-contained underwater breathing apparatus (scuba).

Of the pertinent cardiopulmonary medical problems, five participants disclosed hypertension, 13 allergies, nine asthma, one unspecified congenital heart disease, and two reported a known patent foramen ovale. Regarding surgical procedures, one reported previous heart surgery, one chest surgery, and 22 had previous oral or otolaryngological surgery excluding dental work. A total of 127 (96.2%) of respondents reported having experienced a squeeze. The number of squeezes ranged from 1–200, with an average of eight (SD 20) and a median of 3 (IQR 1–5) squeezes.

SQUEEZE EVENTS

In total, 103 respondents filled out information regarding one or more squeeze events, totaling 140 events reported between 2008–2023 with 55% of events within the 12-months prior to completing the survey. The age at the time of the squeeze incidents ranged from 16–65, with an average of 35 (SD 8) years. The water temperature ranged from 3–37°C, with an average of 23.7°C (SD 6.3) and a median of 25°C (IQR 20–28). Wetsuit thickness ranged from 1–7 mm. The type of breath-hold diving at the time of the incident included training (98), recreational freediving (24), competition (10), safety (2), and fishing (2) (Figure 1). The discipline at the time of the incident included free immersion (51), constant weight (25), constant weight bifins (35), constant weight no fins (11), variable weight (3), and dynamic apnoea (1); there were 14 incidents in which a discipline was not specified (Figure 2).

Excluding the one incident that occurred during dynamic apnoea (swimming just below the surface), the depths of the dives resulting in a squeeze ranged from 10–113 m, with an average target and reached depth of 43 (SD 22) m and median of 38 (IQR 25–57) m (Figure 3). 24 (17%) of dives did not reach the target depth, while 8 (6%) exceeded the target depth. Of all the divers, 23 (16%) were pushing their

Figure 1
Diving type / activity performed during lung squeeze incidents

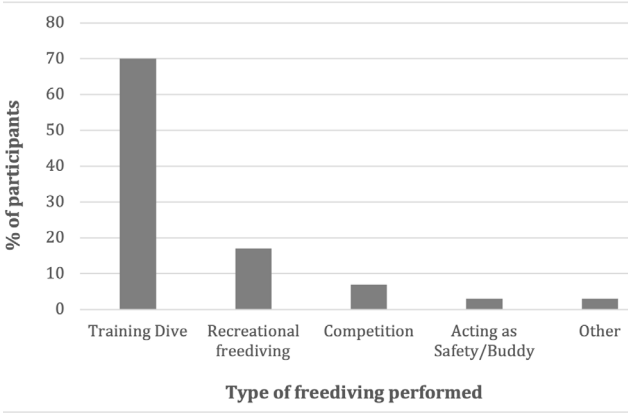


Figure 2
Diving discipline performed during lung squeeze incidents; CWTB –constant weight with bifins; CWT – constant weight with monofin; CNF – constant weight no fins; DYN – dynamic apnoea with monofin; FIM – free immersion; VWT – variable weight; 10% unspecified

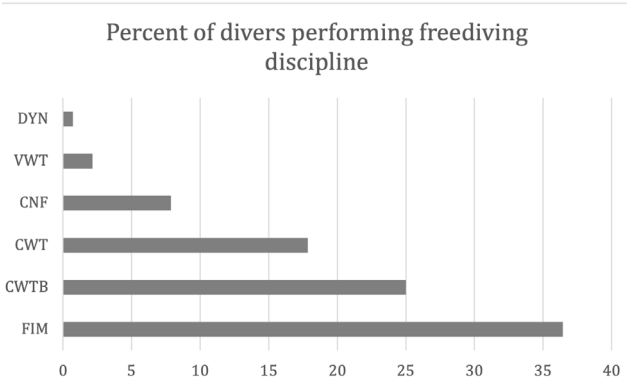


Figure 3
Achieved depth (metres) of dives resulting in a squeeze incident

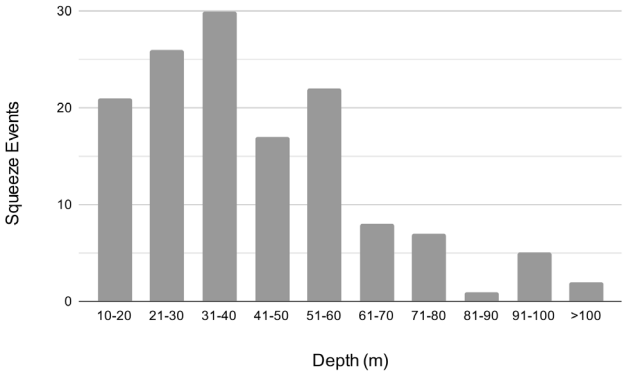


Figure 4
Achieved depth (metres) during squeeze event (grey dots) vs previous personal best depth (black solid line)

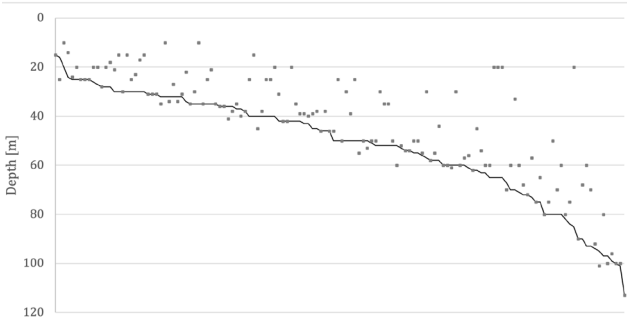
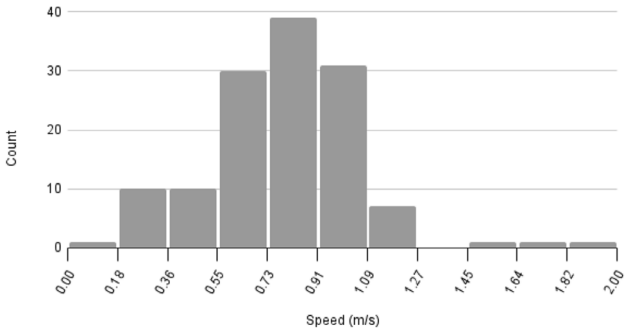


Figure 5
Calculated diving speed of squeeze incidents



personal best depth while 30 (22%) were trying to match a previous personal best depth. Of all the dives, 50 (36%) of dives matched or exceeded a previous personal best (Figure 4). The dive time ranged from 30 seconds to 3 minutes 50 seconds, with an mean of 1 minute 50 seconds. The mean speed of the divers who squeezed was 0.79 metres per second (Figure 5).

Equalisation methods used during the dives included mouthfill (75), reverse packing (14), Frenzel (88), and Valsalva (5). Thirty-five (25%) of divers reported equalisation problems during the incident dive. Of all the divers, 104 (74%) reported diaphragmatic contractions during the incident dive. The mental state of divers during the incident dive was categorised as anxious/stressed/uncomfortable in 31 (22%), doubtful/not confident in 24 (17%), neutral in 41 (29%), or positive in 38 (27%). There was a wide variety of theories of why the squeeze incident occurred (Table 1).

The symptoms experienced during squeeze incidents included cardiopulmonary, otolaryngological, and neurologic complaints (Table 2). Only 4 (3%) squeezes were associated with a blackout. Of all the divers who squeezed, 112 (80%) did not receive any treatment while 25 (18%) received oxygen and 3 (2%) received in-water recompression. Of all

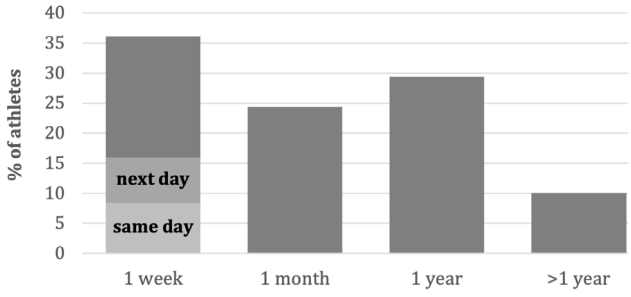
Table 1
Possible contributors to squeeze stratified into three categories

Health and wellness	Preparation and training	Incident during dive
Sleep deprivation (20) Upper respiratory infection (16) Hydration status or hunger (15) Recent squeeze (3) Menstrual cycle (1)	Inadequate warm-up or depth adaptation (29) Diving for too long (16) Pushing personal limit (16) Trouble relaxing (13) Cold water (6) Residual volume dive (1)	Movement at depth (55) Contractions (47) Equalization issue (11) Dive speed (4) Emergency underwater (3) Gear issue (1)

Table 2
Squeeze symptoms stratified within three organ system categories

Cardiopulmonary	Otolaryngological	Neurological
Cough (84) - Hemoptysis (18) Chest tightness (52) Dyspnoea (50) - At rest (29) - With minimal exertion (31) - With heavy exertion (13) Chest pain (6) "*Lung freshness*" (1) "*Felt wet*" (1)	Sputum production (75) - Bloody (57) - Frothy (18) - Thick (5) - Yellow/green (3) - Clear/white (2) Congestion (19) Voice change (11) Throat pain/irritation (7) "*Raspy and gurgly*" (1)	Fatigue (59) Lightheadedness (11) Dizziness (5) Syncope (4) Confusion (3)

Figure 6
Time to return to the same depth after a lung squeeze incident; a third of the athletes returned to their previous depth within a week with a significant number on the same or the following day



the divers who squeezed, 36 (26%) sought further medical attention and 14 (10%) were admitted to hospital. Diagnostic testing included laboratory blood tests (5), radiographs (11), computed tomography (CT) (9), ultrasound (2), magnetic resonance imaging (1), and bronchoscopy (1).

Of the divers who received medical evaluation, four were instructed to get further testing before returning to dive, three were instructed to get repeat X-rays, two were instructed to get repeat CT scans, and one was instructed to get a pulmonary function test. Of the divers who received return-to-dive guidance, 12 were instructed to wait before returning to dive with a range of three days to one year, with a median of one month. The actual time those divers waited ranged from one week to six months, with a median of two months. For all divers regardless of whether they sought medical care, the time until return to the same depth ranged from the same day to four years, with a median of 10 days (Figure 6).

Discussion

This survey captured data from a largely professional group of divers who had experience in freediving instruction and competition for several years. Almost all were certified by one or more freediving organisations, indicating a wide range of freediving training experiences. Almost all respondents had squeezed at least once, indicating a high prevalence of squeeze, even though there were very few divers with underlying medical problems or previous surgeries. We were able to collect data on 140 individual squeeze events over 15 years. It is not surprising that most squeezes occurred during training, as that is a time when divers are pushing their limits or finessing technique within a discipline.

The discipline that required the most movement against resistance (free immersion, which allows use of the arms to pull on the vertical shot line during descent and ascent) resulted in the most squeezes. This is confluent with the respondents' theories that movement at depth was a top

contributor to their squeeze event. These dives may have led to the most squeeze events because the divers were pulling on the rope with more force, thereby straining the thorax more than they would in an arm stroke against the resistance of water.

Most squeeze events occurred on dives shallower than 60 m, with many shallower than the diver's previous personal best depth. This indicates that squeeze can happen even when divers aren't pushing their limits in depth and are likely more affected by other factors during a dive. Many divers cited inadequate warm-up and diaphragmatic contractions from a build-up of carbon dioxide (CO_2) as major contributors to their squeeze event, which agrees with previous reports citing contractions as a major contributor to squeeze.[5] Feeling cold was cited as a rare cause of squeeze, therefore a diver's wetsuit thickness should be appropriate for the water temperature. Carbon dioxide tolerance can be trained over time,[12] but it is unclear how consistent one would need to be with training to build and maintain this adaptation leading up to a dive. It is worth noting that less than a quarter of respondents reported training daily, with a quarter training only seasonally. As this survey did not ask what part of a training season or cycle the squeeze event(s) occurred, it is unclear if these squeezes occurred early in a training season.

In freediving, the standard speed of travel is usually 1 $m \cdot s^{-1}$, though optimal speeds vary between disciplines.[13] For many of the squeeze events reported, the speed of travel was slower than 1 $m \cdot s^{-1}$ which could have resulted in higher oxygen consumption, a more rapid build-up of CO_2, and diaphragm contractions that led to the squeeze. Contractions were cited as the second-highest contributor to squeeze events in this survey. Mental state was cited as a less common cause of squeeze, and > 50% of the squeeze events reported occurred during a positive or neutral mental state, indicating it is a smaller contributor to squeeze. Similarly, 25% of squeeze incidents were attributed to an equalisation issue although most divers utilised mouthfill and Frenzel techniques, indicating equalisation is a lesser contributor to squeeze.

Lastly, it is interesting to note that very few respondents sought medical treatment or evaluation after a squeeze. This follows the current presumption that squeeze events are largely under-reported and under-recognised. Many of the squeeze symptoms could easily be confused for other more common ailments, such as a respiratory infection, or mistaken for other dive injuries, such as decompression illness. That may indicate why a few of the respondents reported receiving in-water recompression as treatment for their squeeze.

A Diver's Alert Network (DAN) workshop on swimming-induced pulmonary oedema and barotrauma of descent in breath-hold diving suggested a general terminology for freedivers who surface with respiratory symptoms: freediving-induced pulmonary syndrome (FIPS).[7] There is still missing information on the exact pathophysiological mechanisms and resolution of the pulmonary pathology that is colloquially called a lung squeeze.

The wide range of diagnostic tests and return-to-diving recommendations speak to the lack of medical guidance on this condition. Most divers who sought medical attention seemed to adhere to a two-month break after a squeeze. However, many more divers who did not seek medical care were able to return to diving at the same depth within a week. The ideal time out of the water after a squeeze remains to be determined.

LIMITATIONS

The authors acknowledge that as with any retrospective survey, there are limitations to consider regarding this data collection. The survey title included the phrase 'lung squeeze', which is colloquially used in the freediving community for barotrauma of descent, it is likely that only freedivers who had experienced a squeeze before took the survey. A prevalence of squeeze injuries in the freediving community can therefore not be established with the existing dataset. Some events that were described occurred months and years before taking the survey; it is common for memories of traumatic events to become slightly modified over time or perceived timelines to be altered.

Conclusions

The findings of this survey suggest that a person who is professionally involved in the sport is very likely to experience a lung squeeze at least once in their career. The severity of lung squeezes varies in respect of signs and symptoms and victims seem to be reluctant to report squeezes or seek medical care after a lung squeeze incident, leaving these events largely under-reported. It is advisable to carefully review the current course content of freediving training agencies and educate freedivers about post-squeeze medical follow-up and return-to-diving recommendations.

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