ANNUAL DIVING REPORT

DAN ANNUAL DIVING REPORT

A REPORT ON 2018 DIVING FATALITIES, INJURIES, AND INCIDENTS

2020 EDITION

DAN
DIVERS ALERT NETWORK

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A report on 2018 diving fatalities, injuries, and incidents

FRAUKE TILLMANS, PHD

Editor

DIVERS ALERT NETWORK

DURHAM, NC

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EDITOR

Frauke Tillmans, PhD

AUTHORS

George Anderson, BS (Appendix C)
Dinesh Ariyadewa (Seciton 3)
Rhiannon Brenner, BS (Section 4)
François Burman, IntPE, MSc (Appendix A)
Peter Buzzacott, MpH, PhD, FUHM (Section 5, Appendix C)
James Caruso, MD (Section 1)
James M Chimiak, MD (Section 1, Section 2)
Petar Denoble, MD, DSc (Section 1, Appendix C)
Grant Dong, B.Sc (Section 4)
Jim Gunderson (Appendix B)
James Grier, MD (Appendix C)
Catherine Harris (Section 3, Section 4)
Elizabeth Helfrich, BS, BA (Section 4)
Akiko Kojima, BA (Section 3)
Yasushi Kojima, MD (Section 3)
John Lippman, PhD (Section 3)
Anna Maese (Section 5)
Marta Marrocco (Section 3)
Alessandro Marroni, MD, MSc (Section 3)
Craig Nelson, MD (Section 1)
Matias Nochetto, MD (Section 2)
Tara Nowroski (Section 5)
Leah Potts (Section 5)
Camilo Saraiva, MD (Section 2)
Frauke Tillmans, PhD (Section 1, Section 4, Section 5, Appendix C)

CONTRIBUTORS

Jeanette Moore
Linda Van de Zande
Lesley Blogg, PhD

DAN would like to thank all the individuals involved in the worldwide diving safety network. This network includes many hyperbaric physicians, DAN on-call staff, nurses and chamber technicians who complete DAN reporting forms. DAN also thanks local sheriffs, police, emergency medical personnel, US Coast Guard personnel, medical examiners, coroners, and members of the public who submit incident data and share their stories.

FOREWORD

While there is no way to entirely eliminate risk while diving, safe practices can mitigate it greatly. And for this reason, they are essential. Part of using safe practices effectively is knowing when, where, and how to implement them. To do so, divers must understand the risks that continue to factor in diving incidents and injuries. At Divers Alert Network (DAN), we strive to create a resource that enables all divers to be informed about what is happening to other divers in the real world and to learn from our experts' insights.

This 2020 edition of the Annual Diving Report is the product of efforts organized by DAN Research, but it is a collaborative undertaking that would not be possible without our many partnerships. DAN Research uses an extensive network of internal and external sources for gathering data on dive injuries and fatalities and works diligently to turn the numbers and facts into meaningful analyses of trends that help divers understand why accidents happen. Contributors from DAN Medical Services are on the front lines of assisting injured divers through the Medical Services Call Center (MSCC), and they use the wealth of cases they handle to offer insight into the mechanisms and resolution of real dive injuries.

Our international partnerships allow DAN to ensure that the report contains information on dive incidents from all over the world and to convey safe diving practices to a global audience. That audience includes anyone who ventures underwater on compressed breathing gas or while breath-hold diving, so the report also reviews breath-hold incidents and highlights our research collaborations on questions at the forefront of freediving safety. A new section from DAN Safety Services expands our attentiveness to equipment failures to improve the usefulness of the report for not only divers but dive professionals and cylinder filling station operators. Reports from various accidents will impart valuable insights for addressing the complex interaction between people and equipment.

There is always more to learn about human health and diving, whether it's a new inquiry into an extensively studied topic like cardiac health or an ongoing effort to observe the impact of a global pandemic on fitness to dive. The DAN Research Update section offers a glimpse at our work to better understand cardiac risk factors and our pioneering survey to evaluate the long-term effects of COVID-19 on diving.

We recognize the resilience of dive professionals and businesses who have adapted their practices to continue training safe divers throughout the pandemic. We also applaud all the divers who remained committed to maintaining their safety awareness and skills despite the challenges, as well as those who could not but are intent on returning to diving safely. This report will help you understand the intricacies of diving injuries and incidents, no matter your situation. Everyone at DAN is committed to providing the community with the knowledge to help divers everywhere stay informed, healthy, and safe.

William Ziefle

DAN President and CEO

SECTION 1.
DIVING FATALITIES

Petar Denoble, James Caruso, Craig Nelson, James Chimiak, Jeanette Moore and Frauke Tillmans

INTRODUCTION

The 2020 DAN Annual Diving Report presents descriptive statistics and selected case summaries of recreational diving fatalities that occurred in 2018. The annual number of deaths, and the mean and median age of victims, are two major trend indicators.

As safe diving practices improve, we hope to see fewer and fewer deaths each year. That said, due to small sample sizes and inconsistent reference data (i.e., number of divers), we have found significant annual variability in reported fatalities. In order to assess the data more accurately, it is best to use information over longer periods of time.

DAN utilizes data collected over the past ten years in an effort to generate more accurate reports. Unfortunately, there is no mandatory reporting for diving-related fatalities, so the final number we report depends on the availability of data and efficacy of the data collection process.

In 2018, fewer reports of scuba fatalities were collected as compared to previous years. The median age of victims has increased rapidly over recent years and has become a reflection of the aging population of divers. Older divers are more likely to have chronic diseases (co-morbidities), which in various ways can contribute to increased scuba and breath-hold diving fatality rates.

Throughout this report, case summaries are used to drive home a message about risk factors and risky behaviors. To protect the anonymity of victims, approximate ages are provided instead of their exact ages, which suffices to frame the case analyses.

Details about scuba and rebreather fatalities are provided in this section. Breath-hold diving fatalities are in Section four.

THE DATA COLLECTION PROCESS

INITIAL NOTIFICATION AND CASE QUALIFICATION

The data collection process begins with an initial notification either from individuals that were aware of the fatality or from publicly available information acquired from active internet searches and automated internet alerts.

Google Alerts are used to monitor online news media outlets for keywords involving breath-hold and scuba related deaths. Sorting through media alerts is tedious work. Regardless of how refined the criteria, the number of redundant or irrelevant reports far exceeds the number of unique accident cases. Other fatality notifications come from individual reports. For example, friends and acquaintances of the victims and DAN members that are aware of DAN's data collection efforts. The DAN Medical Services Call Center (MSCC) is the most valuable single resource. When called, the DAN Medical Services Department assists with diving incident management, regardless of whether the victim is a DAN member.

All reports of recreational compressed gas diving fatalities, that occur in the United States or Canada, or involve United States or Canadian citizens; regardless of location, are followed-up by a DAN staff member. For this report, recreational compressed diving includes: conventional students, certified divers, and diving professionals (i.e. instructors and dive guides), involved in diving that does not qualify as commercial. Rebreather diving fatalities are also reported for recreational compressed gas diving fatalities. Any dive-related deaths that occur outside the United States or Canada and involve citizens of other countries are not followed up on due to logistical constraints.

Non-recreational diving (i.e. military, commercial, fishing, public safety) are not followed up on by DAN staff. Breath-hold fatalities, including freediving and snorkeling, are reported separately and can be found in Section four of this report. DAN attempts to collect as much breath-hold fatality data as possible, when relevant contact information is available, regardless of the geography of the accident or citizenship of the victim.

REPORTS FROM WITNESSES AND NEXT OF KIN

DAN uses the Fatality Reporting Form to collect data from witnesses and family members. The form may be downloaded from the DAN website: **diversalertnetwork.org/files/DivingFatalityReportingForm.pdf**.

When necessary, DAN may contact additional family members to assist in the data-collection process. The family decides whether to complete the Fatality Reporting Form and/or authorize the release of the victim's autopsy report.

The incident reporting form on the DAN website (**dan.org/safety-prevention/incident-reporting/**) may be used to report diving fatalities.

INVESTIGATOR AND MEDICAL EXAMINER REPORTS

Local law enforcement agencies, medical examiners, the coroners office, and both the United States Coast Guard (USCG) and Canadian Coast Guard frequently investigate diving-related deaths in their respective territories. DAN does not conduct investigations of diving fatalities.

Not all victims are subject to autopsies, and sometimes it takes over a year to complete investigations/produce reports. DAN tries to obtain all relevant reports; however, administrative hurdles exist and, in many cases (often due to privacy regulations by investigating agencies) reports cannot be collected, which impedes our ability to conduct analyses.

DATA ENTRY AND ANALYSIS

The DAN Research division maintains the diving fatality data on a secure server. Once all pertinent information has been collected and compiled, the results are analyzed and published in the DAN Annual Diving Report.

NUMBER OF FATALITIES COLLECTED IN 2018

Worldwide, via a combination of internet research and incident reporting, DAN was informed about 189 pertinent deaths involving diving. The number of follow-up (a citizen of, or an incident occurring within the United States or Canada) and non-follow-up cases from 2008 to 2018 are shown in Figure 1-1.

These values indicate that the number of follow-up cases reported in 2018 was less than in previous years, while the non-follow-up cases remained at a similar level. A breakdown of collected cases by DAN diver classifications is shown in Table 1-1 and highlighted in Map 1-1.

GEOGRAPHIC AND SEASONAL DISTRIBUTION OF FATALITIES

The number of follow-up scuba fatalities in the United States, Canada, and other countries for 2018 is shown in Table 1-2. It illustrates a significant drop in the number of reported cases that occurred in the United States and other countries, while follow-up fatalities in Canada remained constant as compared to the 10-year average.

The number of follow-up scuba fatalities in the United States, Canada and other countries for 2018 is highlighted in Map 1-2.

In trying to understand why there are fewer cases for 2018 than in previous years, the data's geographic origin was explored. Table 1-3 shows cases by state in the United States. Florida and California, the two states that consistently had the highest numbers of scuba deaths in the past, averaged fewer cases than the 10-year average. Hawaii reported the most cases in 2018, and Massachusetts stood out with three times as many fatalities than its average over the last 10 years.

In Canada, the number of cases in 2018 was similar to the ten-year average, showing no deviance to the pattern. These results are shown in Table 1-4.

The number of deaths of United States or Canadian citizens that occurred outside their home countries are shown in Table 1-5. Overall, the 2018 average was less than the 10-year average for all participating countries except for Mexico; where a higher number of fatalities were reported. The Grand Cayman Tourism Board confirmed the two scuba fatalities that were reported.

The 2018 data was compared to the 10-year data in three counties within Florida and California that are known for their high fatality counts (Table 1-6). In all six counties the number of fatalities in 2018 was less than that reported for the previous ten years. Information from the San Diego Medical Examiner

Diver Classifications	United States & Canadian	Other	Total
Recreational	55	45	100
Breath-hold	29	30	59
Commercial	6	7	13
Public Safety	1	11	12
Military	0	1	1
Not reported / Unknown	1	3	4
Total	**92**	**97**	**189**

Table 1-1. Total Number of Collected Fatalities Worldwide in 2018 (n=189)

Country	Total Count (2008–2017)	10-year Average	Total Count (2018)
United States	549	55	36
Canada	57	6	5
Other	207	21	14
Total	**813**	**82**	**55**

Table 1-2. Number of follow-up cases in the United States, Canada and other countries for 2018 (n=55)

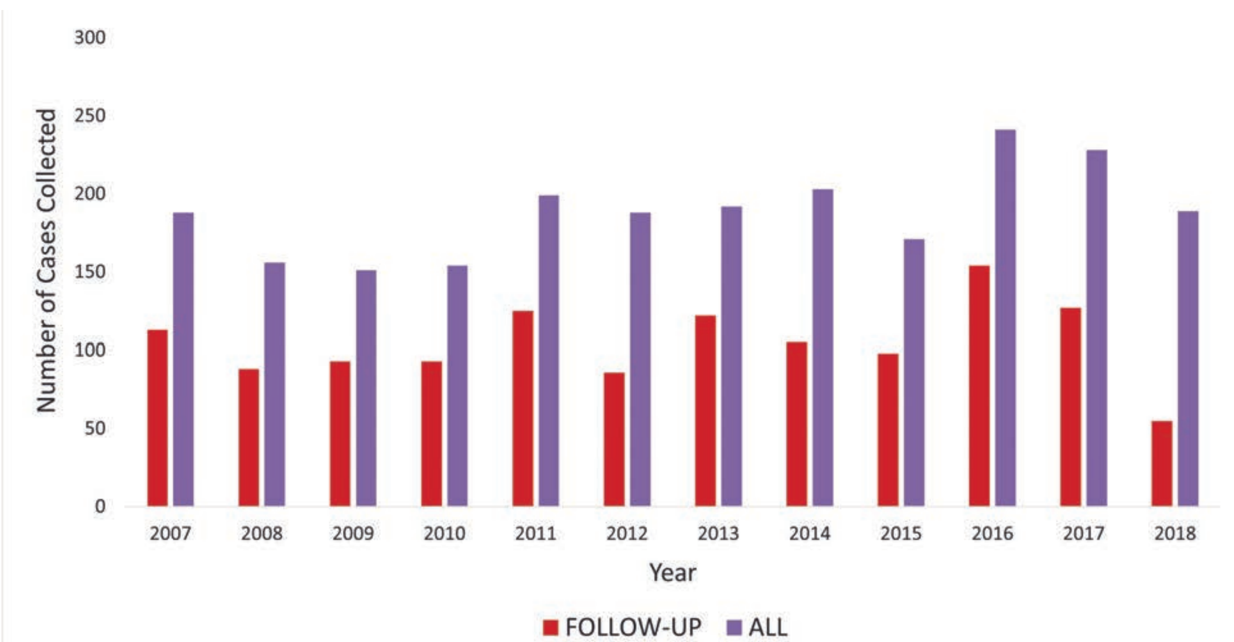


Figure 1-1. Number of Dive Fatalities by Year

State	Total Count (2008–2017)	10-Year Average	Total Count (2018)
Florida	186	19	7
California	102	10	3
Hawaii	40	4	8
Washington	35	4	0
Massachusetts	19	2	6
Michigan	16	2	1
North Carolina	14	1	1
New York	14	1	0
Pennsylvania	14	1	0
New Jersey	13	1	0
Wisconsin	13	1	0
South Carolina	7	1	0
Nevada	7	1	0
Rhode Island	6	1	0
Ohio	6	1	0
Texas	5	1	0
Maine	4	0	0
Oregon	4	0	0
Alabama	4	0	0
Virginia	4	0	0
Illinois	4	0	0
Arizona	3	0	0
Guam	3	0	0
Minnesota	3	0	1
Missouri	3	0	0
Louisiana	2	0	0
Georgia	2	0	1
South Dakota	2	0	0
New Mexico	2	0	1
Arkansas	2	0	0
Tennessee	2	0	0
Puerto Rico	1	0	0
New Hampshire	1	0	0
Kansas	1	0	0
Montana	1	0	0
Utah	1	0	1
Alaska	1	0	0
Wyoming	1	0	0
Oklahoma	1	0	0
Virgin Islands	0	0	1
Vermont	0	0	1
Connecticut	0	0	1
Total	549	55	33

Table 1-3. The Number of reported cases in the United States by the state, for 2018, compared to previous 10-year average. Disclaimer: the cases indicated in the 10-year average were rounded to reflect whole numbers as they pertain to individuals themselves.

(**sandiegocounty.gov/content/sdc/me.html**) indicated two scuba fatalities while DAN's reporting system initially captured only one. The number of fatalities reported directly to DAN's Medical Services Call Center was significantly less, as compared to previous years (see Table 1-7 below).

After a thorough review of the data, it was concluded that in 2018 there were fewer scuba deaths in the United States and Canada than in previous years.

Year	Total Count
2014	30
2015	28
2016	48
2017	58
2018	18

Table 1-7. Total number of divers' death notifications received through the emergency line

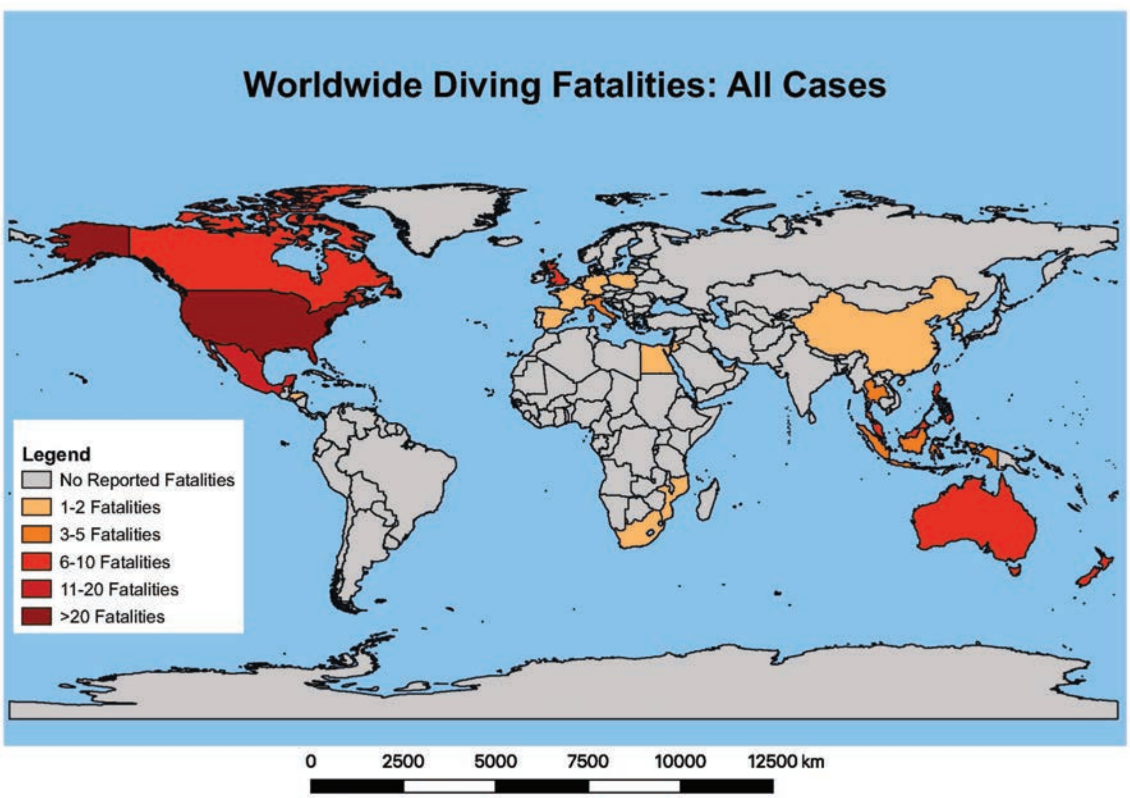
DEMOGRAPHICS OF DECEDENTS

Figure 1-2 shows the distribution of fatalities worldwide, by age and sex. Eighty percent of decedents were male (male, n=44; female, n=11), the average age was 54 years, and the median age was 56 years. A total of 67% of the fatalities recorded were 50 years of age or older. The youngest fatality was 10 years old, and the oldest fatality was 73 years old.

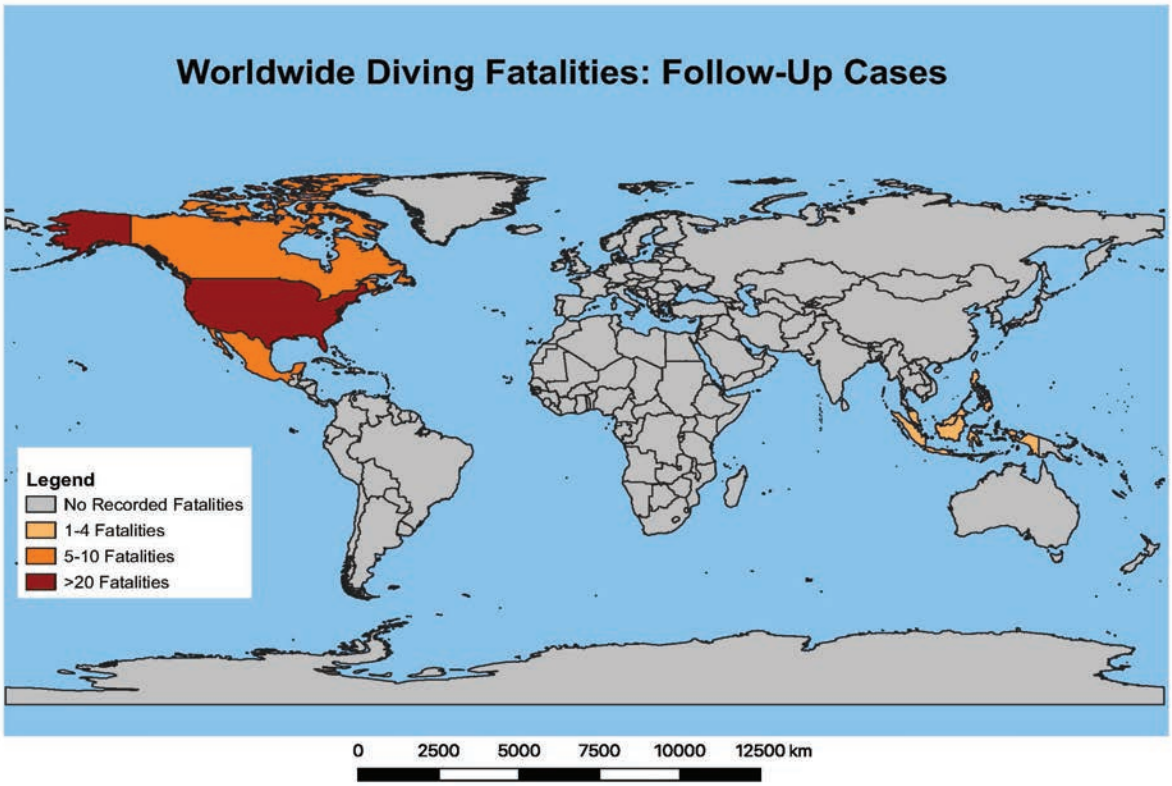
The previously noted trend of increasing age of victims seem to have tapered somewhat after reaching the mean age of 54 in 2015 (see Figure 1-3). While increasing age does not increase fatality risk when diving directly, it may affect health and physical fitness; both of which can indirectly increase risk. It remains however, that for most people, recreational scuba diving can be safely achieved if practiced responsibly.

DAN aims to identify populations that may be at an increased risk of suffering fatal incidents while diving continuously, with the aim of improving safety standards more uniformly over time. While the average age of recreational divers is (in general) rising, there appears to be a plateau at around sixty to seventy years of age, which may correlate with the stabilization of the average age of fatalities.

Other relevant factors, including health history, lifestyle, anthropomorphic measures (i.e. body weight and height), diving certification, and experience level were less available. Most of DAN's knowledge on the health



Map 1-1. Total number of Collected Fatalities Worldwide in 2018



Map 1-2. Number of follow-up scuba fatalities in the United States, Canada and other countries for 2018

Canada Provinces	Total Count (2008–2017)	10-year Average	Total Count (2018)
Ontario	19	2	2
British Columbia	19	2	1
Alberta	6	1	0
Nova Scotia	5	1	0
Saskatchewan	2	0	1
Quebec	2	0	1
Newfoundland and Labrador	1	0	0
Manitoba	1	0	0
Total	55	6	5

Table 1-4. Number of follow-up cases in Canada by province for 2018. Disclaimer: the cases indicated in the 10-year average were rounded to reflect whole numbers as they pertain to individuals themselves.

Country	Total Count (2008–2017)	10-year Average	Total Count (2018)
Mexico	45	5	5
Cayman Islands	30	3	2
Netherlands Antilles	20	2	1
Belize	13	1	1
Bahamas	9	1	1
Indonesia	7	1	1
Philippines	3	0	1
Malaysia	0	0	1
Italy	0	0	1
Grenada	0	0	1
Other	80	8	0
Total	207	21	15

Table 1-5. The number of fatal diving accidents for United States & Canadian citizens occurring in countries outside of the United States and Canada. Disclaimer: the cases indicated in the 10-Year Average were rounded to reflect whole numbers as they pertain to individuals themselves.

State	County	2008–2017			2018
		Total	Mean	Range	
Florida	Monroe	95	9.5	(4–14)	2
	Palm Beach	31	3	(1–5)	1
	Broward	20	2.3	(1–4)	2
California	Los Angeles	49	4.9	(2–7)	0
	Monterey	22	2.2	(1–5)	0
	San Diego	19	2	(1–4)	1(2)*

Table 1-6. Number of U.S cases in counties with most scuba fatalities.

of divers invovled in fatal accidents is obtained from autopsy reports. Less commonly, DAN receives follow-up reports containing fatality information.

CHARACTERISTICS OF FATAL DIVES

The characteristics of a dive are typically comprised of its qualities or features, and serve as key identifiers to the person, place, or type of dive. Dives can be characterized by distinctive marks, focal features, critical attributes, location/topography/region, style, etc. All dives outlined below are categorized by characteristics including platform and environment, spearfishing and harvesting, training, underwater/non-commercial work, and wreck.

In 2018 known fatalities were a direct result of the following diving activities: leisurely diving or sightseeing (n=40), spearfishing (n=4), hunting/game collecting (n=4), training (n=3); and instructing (n=2), and other (unreported) diving activities (n=2).

In 18 cases, dives were made from a vessel with 19 cases orginating from a beach. In 16 cases, the platform was not reported. Most fatal dives occurred in an ocean/sea environment (n=40, 75%), nine in lake or quarry, and two in rivers or springs. In two cases, a description of the environment was missing. At least three instances occurred during wreck diving and one in a cave.

CASES — SPEARFISHING OR HARVESTING

The below cases involved divers that were participating in spearfishing or harvesting; however, the causes of deaths for all four were not necessarily attributed to these activities. All diver fatalities/victims are referred to in the below cases as, Diver 'A'.

Case 2018-009. An experienced male diver in his thirties was harvesting lobster in choppy waters with two buddies. They entered the water at around 10:30 am from the shoreline. All three divers maintained visual contact throughout the dive. It was noted that on two separate occasions, Diver 'A' surfaced and then descended again. Diver 'A' had a precedent of doing this to re-establish location. When the dive was complete, all three divers surfaced together. Diver 'A' then turned on his back, took his regulator out of his mouth, and began a surface swim back to shore. His dive buddies decided to swim underwater to avoid the chop. When the buddies reached shore, they realized Diver 'A' was not with them. They looked back and saw his fins partially sticking out of the water. They swam back and found him face down and at an angle with his regulator out of his mouth. According to the dive computers that Diver 'A' and both of his buddies were wearing, the log shows that Diver 'A' came near the shore but sank beneath the water shortly before the other two divers reached the shoreline. Diver 'A' was underwater for 12 minutes before his body was retrieved. The medical examiner ruled this death a drowning.

Case 2018-021. An experienced male diver in his seventies, was diving solo and using a rebreather to spearfish. A friend who was diving on the other side of the same boat realized that he had not seen Diver 'A' for 30 minutes and started to look for him. He saw Diver 'A' yellow fins at the rear of the boat near the drift line, approximately 20 feet of seawater (fsw) (6.1 meters of seatwater [msw]) below the surface. Diver 'A' looked to be loosely entangled in the drift line, but his mask and regulator were still in place. He was pulled back to the boat and rescue breaths were attempted. Diver 'A' died despite additional medical efforts. It was reported that Diver 'A' had too much weight, his equipment was poorly maintained, and the diluent tank was empty. The medical examiner reported many issues involving his cardiac health (hypertensive and atherosclerotic cardiovascular disease; a stent in the left anterior descending coronary artery; myocardial fibrosis; cardiomegaly; and arterionephrosclerosis), but determined that the cause of death was drowning due to running out of gas and resultant loss of consciousness.

Case 2018-022. An experienced diver in his late forties participated in a spearfishing dive with a buddy. The buddy had a leaky air tank and returned to the raft, where he waited for Diver 'A' to finish his dive. When Diver 'A' did not return, the buddy alerted the harbormaster of a missing diver. His body was recovered the following day. Diver 'A' was reported as healthy prior to the dive. Without a detailed autopsy report available, Diver 'A' was classified as "a drowning from unknown causes" case.

Case 2018-036. A male diver in his late thirties was solo diving for scallops on a dive charter. When he did not surface as scheduled, other divers went back down to search for him. Diver 'A' was found tangled in his buoy line and out of air. The U.S. Coast Guard determined contributing causal factors, including: inexperience diving at the site and diving for scallops; a high rate of air consumption; use of a medication known to cause drowsiness, dizziness, and visual disturbances, insufficient evaluation by the diver and vessel master of the diver's experience level for the scallop dive, entanglement in the dive line, limited self-rescue options as the diver did not carry an emergency source of air or dive knife, and limitations to rescue (as assistance was not readily available to the diver).

CASES — TRAINING

Two divers in their fifties died while training other divers. In one case, an instructor became unconscious and drowned while teaching students at 6.1 msw (20 fsw). In another case, an assistant instructor experienced

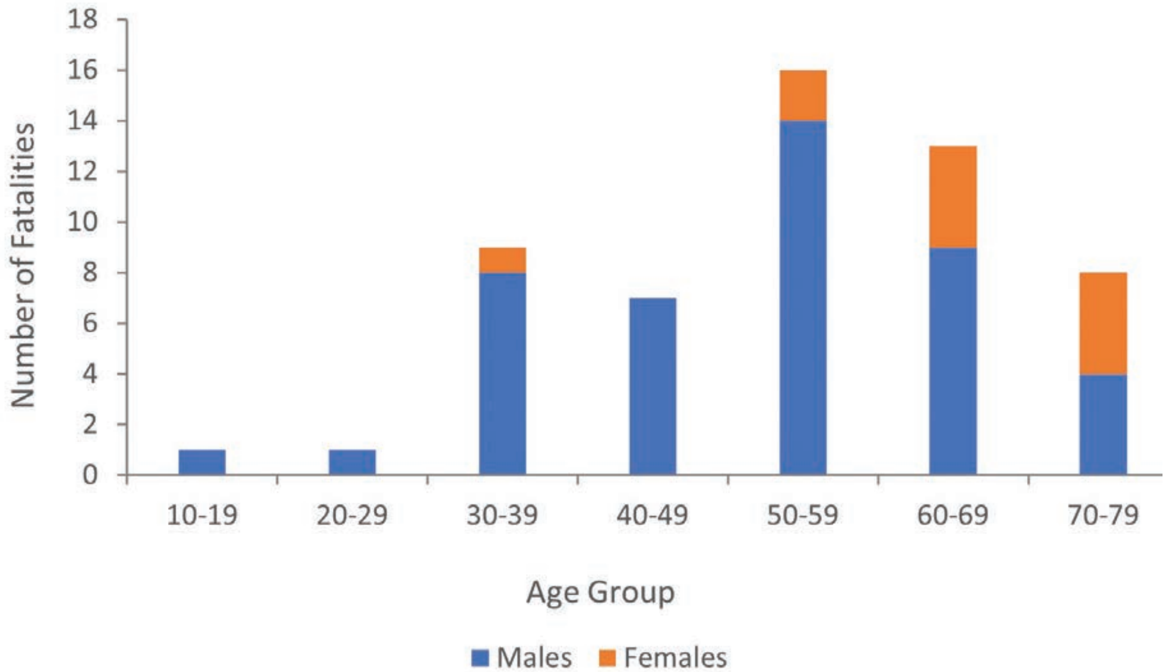


Figure 1-2. Age and sex distribution of reported fatal scuba accidents worldwide in 2018.

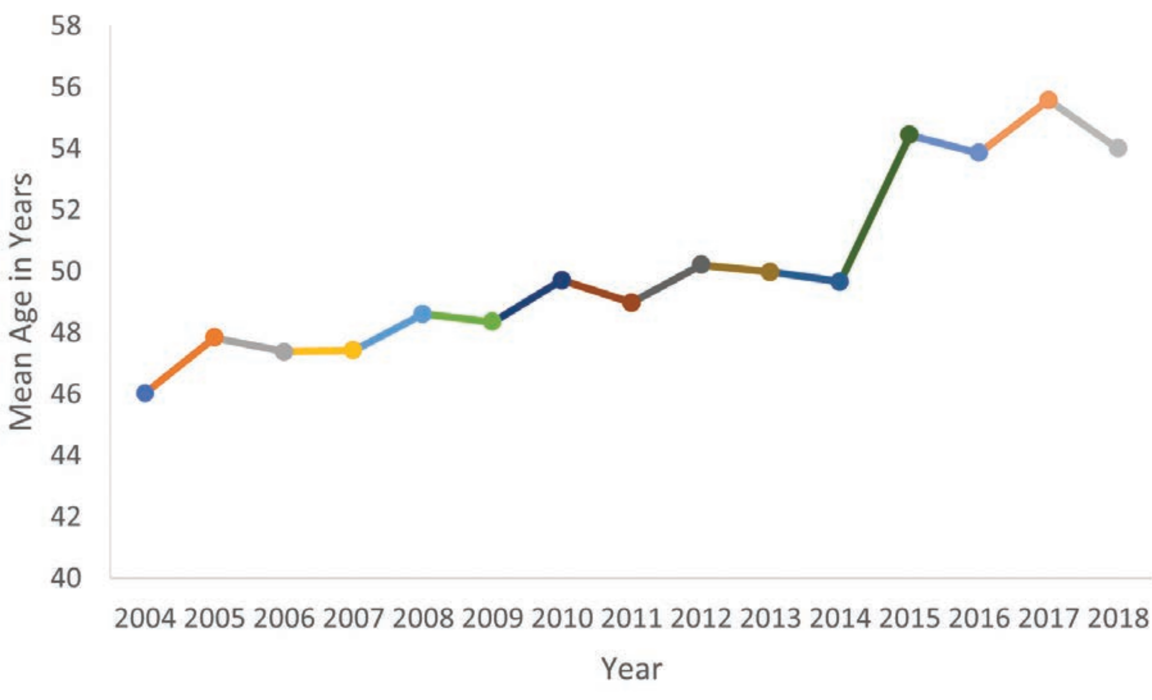


Figure 1-3. Mean age of Fatalities by year (2004–2018).

a heart attack at the surface after a check-out dive with a student.

Additionally, one rebreather training diver died at the start of a rebreather dive, outside of supervised instructional time.

Case 2018-010. A male diver in his thirties died in a rebreather diving incident. He had started training on a rebreather six months prior and had 100 hours on the unit. He was a student participating in a trimix class but was reportedly not being supervised by an instructor when the incident occurred. Diver 'A' was on the surface talking with the boat crew while another diver went down to check visibility. A divemaster noticed Diver 'A' descending rapidly without his mouthpiece in his mouth. Reports are unclear as to whether the diver who checked for the sites visibility was also the divemaster who noticed Diver 'A' descending. The divemaster swam after Diver 'A', caught up with him at a depth of 38 msw (124 fsw), and brought him back to the surface. The boat crew initiated cardiopulmonary resuscitation (CPR) and transported Diver 'A' to the hospital where he was pronounced dead. The oxygen cylinder of his rebreather was not turned on. Diver 'A' was obese (BMI 33.1), but the medical examiner did not find any other major health issues. The cause of death was ruled as drowning due to hypoxia and loss of consciousness.

Case 2018-019. A male student in his late fifties was diving with a dive instructor. They were practicing switching from primary to secondary regulator when the instructor noticed Diver 'A' was having problems (not indicated what type of problems), so, the instructor brought him to the surface. On arrival at surface Diver 'A' was not breathing and CPR was started, but the victim never recovered. He was pronounced dead at the scene. The autopsy was not available. The cause of death remains unknown.

Case 2018-035. A female diver, in her early fifties, was completing her deep-water certification when she did not surface. The news report said she did not respond to the instructor's signal to surface. No other details were available regarding the dive. The autopsy revealed complications of drowning, obesity (BMI 34.2), and hypertensive cardiovascular disease with mild cardiac hypertrophy (430 gr); as well as slight left ventricular hypertrophy (1.5 cm). It is likely that a disabling cardiac event occurred preceding drowning, which was ruled to be the cause of death.

CASES — NON-COMMERCIAL UNDERWATER WORK

Case 2018-011. A male diver in his forties was assisting with the retrieval of a tractor that fell into a canal, which was a maximum of 20 feet (6.1 m) deep. He was tied to a rope with an onshore tender. When the tender noticed the diver was staying underwater longer than expected, he pulled on the rope and found that the diver was dead. An autopsy was conducted; however, neither autopsy nor investigation reports were available.

Case 2018-045. An experienced male diver in his mid-sixties was diving with a colleague from a kayak. Diver 'A' surfaced after being down to 80 fsw (24 msw) for 20 minutes while repairing a mooring buoy. Upon emerging, he said that he did not feel well. Witnesses reported foam coming out of his mouth. Diver 'A' removed his weight system and attempted to remove the rest of his gear, but collapsed suddenly. A friend towed him to shore and called for help. Despite the response of emergency personnel and CPR efforts, Diver 'A' died at the scene. The medical examiner reported obesity (BMI 32.1), cardiomegaly (600 g), left ventricular hypertrophy (2.1 cm), and hypertensive cardiovascular disease. The medical examiner determined the cause of death as asphyxia due to drowning. DAN reviewers established immersion pulmonary edema (IPE) as both the disabling condition and the cause of death.

CASES — WRECK DIVING

Case 2018-012. A male diver in his late thirties was solo diving a wreck located at about 90 fsw. When he was overdue returning to the dive boat, a rebreather diver went down to look for him and found Diver 'A' entangled in a line. He put a regulator from a bailout tank in the mouth of Diver 'A', untangled him, and ascended. The rescue diver said he was breathing on the way to the surface. Once at the surface, Diver 'A' began vomiting but was conscious and speaking. The rescue was hampered by challenges with getting the diver onboard the vessel due to his body mass (136 kilograms/300 pounds). He was brought aboard, taken ashore (five-minute boat ride), and transferred to a waiting ambulance. Diver 'A' was then taken to the hospital, where he died shortly after arrival. Reports indicated that he had suffered a medical event either on the way to the surface or on the way to the hospital, but medical documentation could not be obtained to confirm this.

Case 2018-023. Diver 'A' was an experienced diver in his late sixties. He reportedly ran out of air while diving a shipwreck at 130 fsw (40 msw). He shared air for a time with another diver. The report does not indicate how long both divers shared air, nor does it make clear why the divers did not ascend immediately. Eventually, the other diver ascended and told people on the surface about Diver 'A' being left behind. A different diver went down and found Diver 'A' dead at the bottom. The autopsy revealed a blunt force injury, hypertensive and atherosclerotic cardiovascular disease, and cardiomegaly. The medical examiner determined the cause of death as drowning due to running out of gas. The head injury remained unexplained.

Case 2018-029. A male diver in his late forties was diving a wreck at the bottom of a lake (26.5 meters/87 feet deep). Upon surfacing, the Diver 'A' struggled to remove his diving helmet and, after a short time, became limp. His friends hauled him back on the boat. They had difficulty removing the helmet as they were not familiar with it. Diver 'A' was unconscious. His friends began CPR and brought him ashore where he was taken to a hospital and pronounced dead. Upon examination of his Go-Pro video and his dive computer profiles, the investigator concluded that the victim was either very low on or out of it and that he surfaced too quickly from a depth of 18 mfw (58 ffw). His ascent rate, as recorded by the dive computer, was 31 m/min (102 ft/min.) Information about tank pressure was not available. An autopsy was done, but the report was not released. A rapid ascent is often associated with an arterial gas embolism (AGE). However, the trigger for the emergency ascent after a relatively short dive, remains unknown.

ANALYSIS OF SITUATIONS AND HAZARDS

FATALITIES BY DIVE PHASE

For the purpose of analysis, we use the following dive-phase categories: on the surface before diving, during the dive (including descent and ascent), and on the surface after diving. Dive-phase information was either directly or indirectly available in 41 of the 53 cases (79%).

In 29 cases the problem was noticed underwater by the affected diver or by another diver. In 13 cases, DAN was able to establish the following as a likely trigger:

- Cardiac events (3)
- IPE (2)
- Out of air (2)
- Entanglement (2)
- Nitrogen narcosis (1)
- Rapid ascent resulting in AGE (3)

PRE-DIVE

When death occurs at the surface before descent (pre-dive), the question arises as to whether it was coincidental or had a causality related to the dive. Pre-dive death happened in two cases, that are explained in more detail (Case 2018-008 below and Case 2018- 010 on page 10.)

Case 2018-008. A female in her thirties stopped moving after she dived into the water. The divemaster with her noticed and immediately brought Diver 'A' back to the boat. She was rushed to the nearest hospital, but could not be resuscitated. This sudden death may have been caused by a variety of reasons, but most likely was of cardiac in nature, and the immersion was likely the provocative factor.

ASCENT

In the four cases listed below, witnesses became aware that the ascending diver had developed a problem while coming up from his or her dive. However, one could argue that the divers decided to ascend because of the issues experienced while at depth.

Case 2018-017. Diver 'A' was an uncertified young boy who was diving with his father. He was breathing from his father's spare regulator. At 7.6 mfw (25 ffw), Diver 'A' suddenly dropped the regulator and swam quickly to the surface. At the surface, he experienced an undisclosed medical emergency and later died on his way to the hospital. Diver 'A' most likely panicked, rushed to the surface while holding his breath, developed a lung overexpansion injury (also known as lung barotrauma), and died due to the AGE.

Case 2018-024. An experienced male diver in his late sixties signaled that he was out of gas 15 minutes into a dive to 9 msw (30 fsw) breathing enriched air (nitrox). Reports are unclear to whether Diver 'A' and his buddy shared air or if he used a backup air source as they surfaced. Upon reaching the surface, his buddy reported that Diver 'A' seemed agitated and was mumbling incoherently. Diver 'A' lost consciousness while waiting for retrieval and sank before his buddy could get to him. The inspection of the diver's equipment revealed no reason for the breathing difficulty. Diver 'A' had sufficient reserve (162 bars/2350 psi) in his air tank, thus, the breathing problem he experienced was due to acute health issues and not to a lack of gas in his tank. The autopsy report noted a BMI of 24.6, little atherosclerosis, and some myocardial fibrosis. The report mentions "heavy lungs, filled with foam" and fluid present in the lungs and airways. Toxicology tests identified two blood pressure medications and opiates. The cause of death ruled by the medical examiner was cardiac-related death, while the DAN reviewers qualified it as immersion pulmonary edema (IPE).

Case 2018-030. A male diver in his sixties was diving with a group to 20.3 msw (61 fsw) when he reportedly noticed his air tank was approximately half empty. Diver 'A' signaled to his dive guide that he was going to ascend. At the surface, the boat crew realized he was unresponsive and jumped in to retrieve him and bring him back to the boat. The crew started CPR and recalled the remaining divers in the water. Diver 'A' was taken to the hospital where he was pronounced dead. The medical examiner established cardiac arrest as the cause of death. Other findings include obesity (BMI 31), high blood pressure, left ventricular hypertrophy, and cardiomegaly.

Case 2018-039. A male diver in his late fifties surfaced from a dive and was reported to have foam coming from his mouth. CPR was performed for 45 minutes. Diver 'A' was taken to the hospital where he was pronounced dead. In this case, while the witnesses became aware of Diver 'A' having problems upon ascent, it is suspected that IPE started before his ascent.

POST-DIVE

Three divers surfaced, exited the water, and lost consciousness. In all three cases, sudden cardiac death is most likely the cause of death, but in Case 2018- 038, we do not have any details to substantiate that assumption.

Case 2018-037. A male diver in his early seventies got back on the boat after a dive and complained that his suit felt too tight. He was assisted out of his suit and was given oxygen, after which he said that he felt better. However, a few minutes later, a crew member noticed Diver 'A' slumped over and unresponsive. The divemaster attempted CPR, and the diver began to vomit. CPR was resumed during transportation to the hospital, where the diver was pronounced dead upon arrival. Sudden tightness in the chest may have many causes, but with rapid progression to death and without other accompanying symptoms, it was presumed a likely sudden cardiac death.

Case 2018-038. A male diver in his fifties collapsed on the boat after returning from a dive and could not be revived. No additional details could be obtained.

Case 2018-040. A female diver in her sixties, accompanied by her husband, was diving to 18.3 msw (55 fsw). After several minutes, she signaled that she was out of air. The husband and the divemaster offered their secondary regulators to Diver 'A', which she declined, insisting on ascending. The divemaster noted that Diver 'A' had 2000 psi left in her tank. He assisted her in a controlled emergency surface ascent. Reports do not indicate whether Diver 'A' continued breathing from her own regulator after being informed of her remaining air, nor does it specify if she accepted a secondary regulator for the emergency ascent. At the surface, she was conscious and answered questions, in short, one-word responses. After boarding the dive vessel, she became unconscious, apneic and pulseless. CPR was initiated without success. Diver 'A' was declared deceased at the hospital.

TRIGGERS, MECHANISMS OF INJURIES, DISABLING INJURIES AND CAUSES OF DEATH

When it comes to rare disasters with a substantial societal impact, teams of experts engage in a systematic investigation to discover causes and prevent similar occurrences in the future. Usually, in industries that have built-in robust safety measures and routinely log every activity, the analysis goes step-by-step down the chain of events trying to establish why the safety system failed, a process known as a "root cause analysis". Diving fatalities mostly involve a single victim and thus, do not receive the same priority over other fatalities.

The regulation of recreational activities is weak, the documentation inadequate, and available evidence rarely suffices for a thorough root cause analysis. That said, the study of the chain of events in diving fatalities can identify potential targets for preventive interventions.

The analysis often goes backward from the outcome to the roots. Along the way, all identified contributing factors are recorded for statistical analysis.

In this report, we will focus on final cause of death as reported by medical examiners, and try to identify disabling injuries, mechanisms of injuries, and likely triggers.

CAUSES OF DEATHS

For 25 cases DAN was able to retrieve either the autopsy reports (n=18), the investigative report (n=15) or both documents for analysis. The cause of death (COD), as specified by the medical examiner, are shown in Figure 1-5.

Of 15 cases where drowning was the COD, six cases indicate that drowning was also the disabling injury. Three occurred due to running out of gas while unable to reach the surface, and one diver sank due to inadvertent release of air from his BCD. In two cases, there was no other explanation. Medical examiners also declared a cardiac-related cause of death in four cases, AGE in two, IPE in two, and intoxication in one. However, from the prevention point of view, DAN is more interested in disabling injuries that preceded death.

DISABLING INJURIES

Disabling injury or illness (DI) is directly responsible for incapacitation and death due to drowning when it occurs in water. When a death occurs after the diver leaves the water, the COD and the DI are often the same. Disabling injuries established for the 2018 fatalities are shown in Figure 1.6

Since many diving fatalities occur without a witness and/or autopsies being performed, in 36% of cases, the DI remains unknown. In those with available details, there were 12 instances of heart conditions being the leading DI: six diagnoses were confirmed by autopsy, and six were established based on accident scenarios.

CARDIAC CONDITIONS

Medical examiners reported cardiomegaly (an enlarged heart) in eight cases; however, the reference values were not reported. The heart's weight in healthy people is generally proportional to body size expressed as weight, height, or body surface area (BSA). Still, there is a great level of variability.

Age and illness additionally affect the size of the heart. Reference values are based on various sample measurements and vary depending on size, makeup, and ethnic origin. We compared the heart weights of eight cases with two sets of reference values to determine if cardiomegaly was present.[2, 3]

Four cases met criteria outlined by Vanhaebost et al. (2014) and one case outlined by Wingren et al. (2015). Some medical examiners may adopt a simple rule that a heart weight greater than 500 grams indicates cardiomegaly and a left ventricular wall thickness of 1.5 cm or greater indicates left ventricular hypertrophy (LVH).[1]

Other medical examiners may defer to the appearance of the heart, microscopic changes in heart muscle, and the presence of factors that might cause the heart to work harder, increasing its muscle mass.[1] The latter was assumed to be utilized by medical examiners in most cases in our dataset.

In Table 1-9, we show the presence of obesity, hypertension, LVH, and significant atherosclerotic coronary disease, all of which were ruled cardiomegaly. Additionally, extensive co-morbidities were present in all cases.

While it is not known whether these parameters played a role in the medical examiner's diagnosis of cardiomegaly, such specific data diagnosis helped DAN's reviewers establish cardiac issues as the disabling condition.

The largest heart observed was in Case 2018-031 (see below), and is classified as cardiomegaly according to all three references.[1, 2, 3]

Case 2018-031. A male diver in his fifties surfaced after a dive and yelled for help before losing consciousness. He was transported to the hospital where he was pronounced dead. He had a history of past methamphetamine abuse in addition to several chronic conditions, including: congestive heart failure, asthma, hyperlipidemia, and hypertension. The official cause of death was acute methamphetamine toxicity. His heart weighed 710 grams.

In satisfying the criteria outline by one of three references, three more cases classified cardiomegaly.

Case 2018-006. A male diver in his late fifties was diving alone with a companion on land as shore support. About an hour later, a group of freedivers saw his body lying motionless on the seafloor. He was about 30 yards from shore, in roughly ten fsw. and was still in all of his scuba gear. The freedivers called for help and retrieved his body. Resuscitation attempts failed, he was pronounced dead at the scene. The diver was morbidly obese (BMI 45), had a history of high blood pressure and a stent placed in his right coronary artery. He also had indications of cardiomegaly (630g) and myocardial infarction.

Case 2018-045. (see page 11)

Case 2018-002. A male diver in his late sixties came to the surface following a dive to 55 fsw. His buddy noticed some blood on the mask of Diver 'A' and warned him. Diver 'A' cleared his mask, and both divers proceeded to swim towards the boat. Diver 'A' indicated that he was having difficulty breathing and the buddy started towing him to the boat. Diver 'A' lost consciousness just as they reached the boat. The crew assisted in bringing him on board and administered CPR. Once back at shore, Diver 'A' was transported to the hospital where he was pronounced dead. Diver 'A' had a history of high blood pressure and a recent cold. His heart weighed 550 g. Toxicology reports showed that the diver tested positive for barbiturates and hydrocodone and that he had extensive coronary heart disease.

Arterial Gas Embolism (AGE) was established as the disabling injury in six cases. In Case 2018-001, the medical examiner reported death due to air embolus in the heart. Other information was not available.

Case 2018-003. A trained cave diver in his fifties died while diving in a familiar cave system. The incident happened at about 51 meters (170 ft) deep. Diver 'A' and his buddy had turned for the swim back when the buddy noticed that he was having trouble reeling in his line. He waited for Diver 'A' to resolve the problem when he noticed Diver 'A' suddenly ascend and resultantly stir up silt in the water. The buddy deployed his safety reel and went to assist. He found the victim at the ceiling with his regulator out of his mouth. The buddy purged the regulator and tried to replace it in the victim's mouth, but the victim was unresponsive. The buddy unwedged Diver 'A' and sent him to the surface while he completed his decompression before surfacing and calling for help. Another diver recovered the body of Diver 'A'. The medical examiner ruled the cause of death as drowning. DAN reviewers considered subcutaneous emphysema reported by the medical examiner, panic, and a rapid ascent from 53 meters to about 9 meters (175 to about 30 ft); as well as AGE as likely disabling injuries. The victim also had a head injury, which could have rendered him unconscious and caused drowning.

Case 2018-014. According to witnesses, a male diver in his forties surfaced in distress and ceased breathing before his buddy and witnesses could get him to shore. The buddy stated that Diver 'A' appeared to be struggling with buoyancy or was running low on air when he signaled to surface. They attempted to do a safety stop, but Diver 'A' ascended rapidly, and the buddy followed. Rescuers and

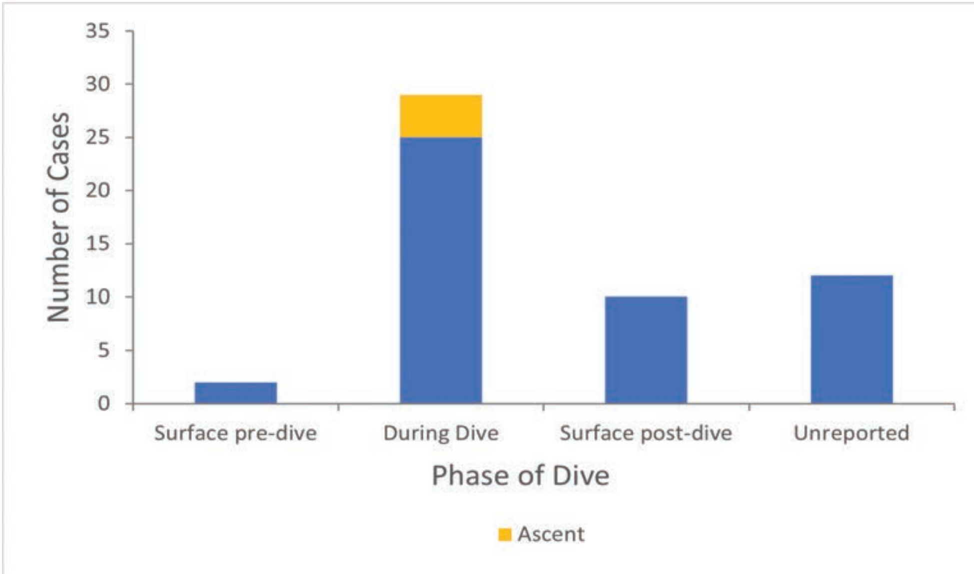


Figure 1-4. The distributions of the phase of the dive when the problem became apparent. Four of the 29 cases where the issue became apparent during the dive happened during ascent.

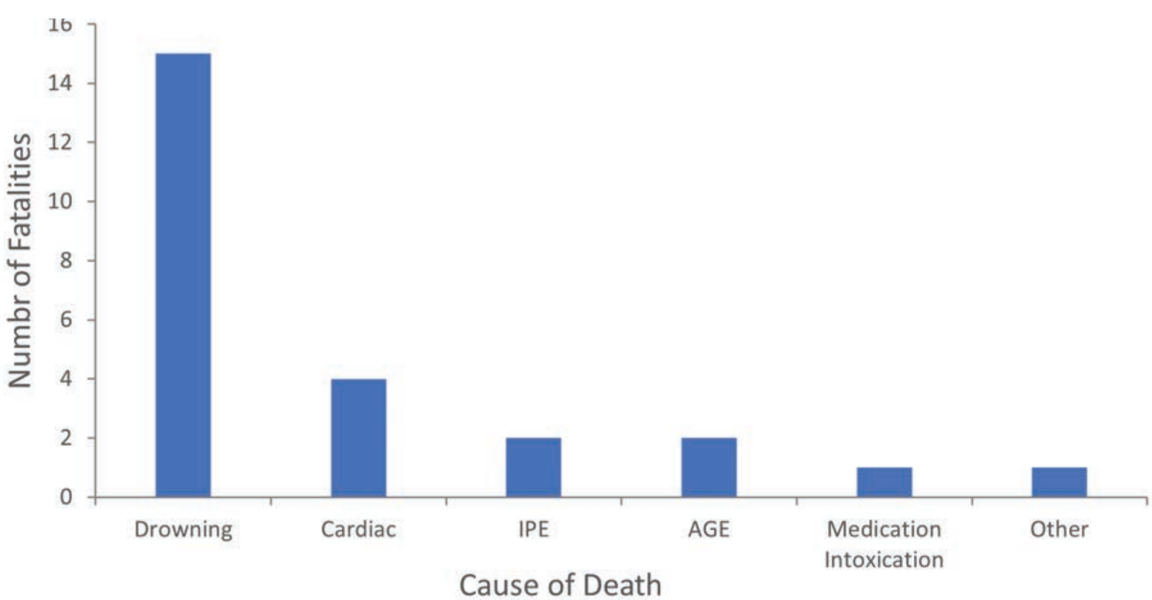


Figure 1-5. Cause of death as reported by medical examiners

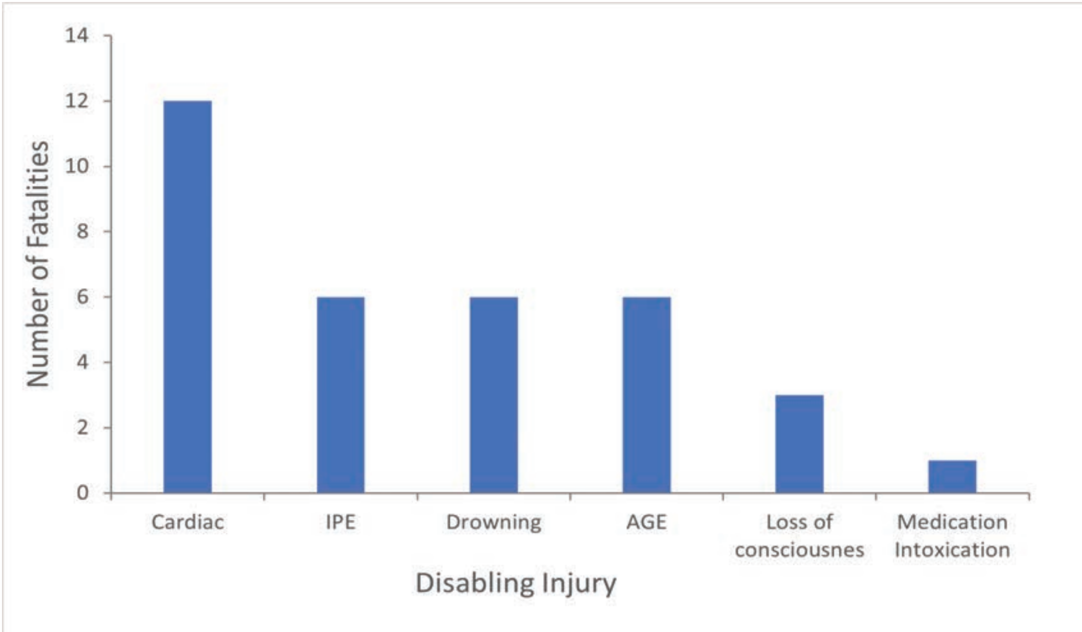


Figure 1-6. Disabling injury (DI) or medical condition preceding death

EMS administered oxygen and CPR but were unable to resuscitate him. The autopsy report was not available.

Case 2018-017 is described on page 12 and **Case 2018-029** on page 11.

Case 2018-047. A male diver in his sixties descended to about 70 fsw with a group. His buddy noticed him swimming away from the group and downwards. She tried to catch up with Diver 'A' but began feeling tired before reaching him. The buddy estimated that they were at 56 meters (185 fsw) when she noticed that Diver 'A' was no longer swimming, rather he was slowly sinking, vertically. The buddy recalls being assisted by other divers to the surface at this point. The instructor and other witnesses indicated later that Diver 'A' continued to descend and ran out of air. He had to pull his emergency cord, sending him up too rapidly. The report does not indicate whether or not this was in an effort to drop weight. Witnesses saw Diver 'A' "popping" out of the water. He likely suffered from nitrogen narcosis, and most likely died of AGE.

DROWNING AS DISABLING INJURY AND CAUSE OF DEATH

Drowning as the disabling injury and the cause of death was established in six cases.

Case 2018-020. A male diver in his early fifties surfaced from a dive to 30 fsw and reportedly noticed a weird sound coming from his BCD. Diver 'A' asked for assistance from his buddy to fix the noise/leak. They inadvertently loosened the cap too much, and all of the air was released from the BCD. Diver 'A' lost buoyancy and sank. The buddy attempted to go after him but was unsuccessful. Diver 'A' was recovered later at the bottom, with his regulator out of his mouth. He had a weight system with 20 lbs of weight still attached. It is assumed that in an effort to try and gain buoyancy, Diver 'A' overinflated his BCD manually.

Case 2018-042. A male diver in his early fifties was diving solo to collect fossils and rocks. When he failed to return to the dive boat, a search was initiated, but he was not found until the following day. The scuba tank and pony cylinder of Diver 'A' were both empty. After evaluation, his gear was reportedly poorly maintained. The autopsy did not reveal any other possible cause of death besides drowning. Toxicology testing found the following: trace amphetamine, caffeine, chloroquine, citalopram, and quinine. All of these were consistent with therapeutic use and not relevant to the death.

The other four cases (**2018-009, 2018-022, 2018-023, & 2018-036**) have been described earlier in the chapter.

DISABLING INJURY— IMMERSION PULMONARY EDEMA (IPE)

IPE was the suspected disabling injury in six cases. Four cases involving males were described earlier in this chapter.

Case 2018-051. A woman in her seventies with unknown diving experience indicated she wanted to surface from 60 fsw. When Diver 'A' and her buddy reached the surface, she started foaming at the mouth and had to be pulled from the water. Despite resuscitative attempts, death was pronounced at a local hospital soon after. The autopsy did not reveal any preexisting disease.

DISABLING CONDITION— LOSS OF CONCIOUSNESS

Cases 2018-010 and **2018-021** (page 10) both occurred with rebreather diving.

Drug-related deaths were suspected in two cases. In both cases, the drug was methamphetamine (see Case 2018-031).

Case 2018-015. A male diver in his early fifties was diving with a buddy when he suffered medical distress and surfaced. His buddy did not see what happened to Diver 'A' but swam over to assist him and found him unconscious and unresponsive with his face underwater. The buddy attempted to rescue the Diver 'A', but he sank to about 16.6 meters (50 feet) of depth. Another diver found him and brought him ashore about an hour later. Based on the lack of natural disease signs and positive toxicology tests, the medical examiner ruled acute methamphetamine intoxication as cause of death. Diver 'A' probably lost consciousness due to cardiac issues, which methamphetamine use can cause.

Methamphetamines can have effects on multiple organ systems. For divers, it is especially important to be aware of the cardiovascular effects of methamphetamine. An increase in catecholamine activity in the peripheral nervous system may be a consequence of methamphetamine use. The peripheral nervous system is responsible for modulating heart rate and blood pressure. High levels of catecholamines can cause narrowing of bloods vessels, increased heart rate, high blood pressure, and possibly myocardial infarction. The formation of fibrous tissue and increased size of heart muscle cells are features of catecholamine toxicity.[4]

SUICIDE

Case 2018-027. An experienced male diver in his sixties went diving with two young relatives. They encountered strong currents and decided to abort their dive. They were swimming back to shore when the two buddies realized that Diver 'A' had disappeared. His body was recovered at the bottom with a dive flag wrapped around him. Diver 'A' had a history of depression and panic attacks. The medical examiner ruled the death as suicide by an overdose of sertraline. Some of our reviewers suspected that Diver 'A' may have used sertraline to treat a withdrawal of Xanax (used to treat panic or anxiety), which may have caused agitation, confusion, drowsiness, and panic; all of which are likely to occur when facing a strong outgoing tide.

MECHANISMS OF INJURIES AND TRIGGERS

The chain of event analysis helps us to better understand accidents. Details referencing specific cases were discussed earlier this chapter with the events and mechanisms invovled are shown in table 1-10 and triggers are shown in table 1-11.

Age	Sex	Height (cm)	Weight (kg)	Heart Weight (grams)				
				Measured	Vanhaebost et al, 2014.		Wingren et al, 2015.	
					Predicted	Upper limit	Predicted	+1 StdDev
53	male	162.6	76.7	710	362	447	390.9	452
57	male	180.3	147.4	630	493*	578*	632.4	743
64	male	190.5	116.6	600	457	548	591	694.3
68	male	177.8	105.7	525	432	518	553.2	650
73	male	172.7	99.3	490	417	503	546.1	641.7
67	male	180.3	93.4	480	402	488	495.8	573.2
72	male	182.9	104.3	480	427	513	574.2	674.7
73	male	170.0	110.0	460	443	528	570.2	669.9

Table 1-8. Heart weight and reference values in eight cases with cardiomegaly determined by a medical examiner

Age	Sex	Ht (cm)	Wt (kg)	BMI	High blood pressure	Left ventricular hypertrophy	Cardiomegaly (grams)	Coronary heart disease (>75% stenosis)
53	male	162.6	76.7	29.0	+	1.7	710	-
57	male	180.3	147.4	45.3	+	1.6	630	+
64	male	190.5	116.6	32.1	+	2.1	600	-
68	male	177.8	105.7	33.4	+		525	+
73	male	172.7	99.3	33.3	+		490	+
67	male	180.3	93.4	28.7	+		480	+
72	male	182.9	104.3	31.2	+	2	480	-
73	male	170.0	110.0	38.1		1.4	460	+

Table 1-9. Contributing medical conditions in eight cases with cardiomegaly

Harmful Event/ Mechanism	n
Rapid ascent	4
Natural disease	5
IPE	3
Insufficient breathing gas	3
Arrhythmia due to methamphetamine	2
Other	3
Unknown	29
Lack of buoyancy	1
Hypoxic breathing gas	1
Suffocation	1
Cardiac Dysrhythmia	1

Table 1-10. Harmful Events or Mechanisms of injury

Trigger	n
Immersion	3
Low on air	3
Exertion	3
Drug use (methamphetamine)	2
Equipment problem	2
Intrinsic	5
Closed oxygen cylinder	1
Struggle and Entanglement	2
Nitrogen Narcosis	1
Rough Seas	1
Unknown	30

Table 1-11. Trigger Events of Injuries

CONCLUSION

Most scuba fatalities occur in older divers and are related to health and fitness issues. A healthy lifestyle, staying fit, and regular medical checkups are pre-requisites for lifelong, healthy, participation in scuba diving.

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SECTION 2. DIVING INJURIES

Matias Nochetto, Camilo Saraiva, James M Chimiak

MEDICAL SERVICES CALL CENTER (MSCC)

DAN was established in 1980 to assist injured divers. It started as one medic receiving phone calls and engaging volunteer physicians as needed. Today, DAN's Medical Services Call Center (MSCC) has a team of medics, nurses and physicians operating at two strategic locations to provide adequate coverage to DAN members and divers in need around the world, 24/7. The assistance includes recommendations during pre-hospital management[1], emergency room evaluation, treatment, and disposition of injured divers.

HOW DAN ASSISTS WITH THE MANAGEMENT OF DIVING INJURIES

DAN Medical Department receives 11,000 inquiries per year on average, where around 3,600 inquiries pertain to divers experiencing symptoms following a dive. Most calls typically originate from lay people (injured diver, a fellow diver or dive leader, family member, etc.) before they have seen any medical professional. Assessment of the situation and a thorough telemedicine triage becomes the essential first step for proper case management. Our medics, nurses, and doctors with training and experience in diving do their best to establish clinically relevant facts in communications with callers, and to provide best advice.

A percentage of the calls come from healthcare professionals (ER physicians, nurses, or chamber staff) seeking expert dive medicine consultation when examining an injured diver. DAN's role in these cases is far less challenging as the information conveyed for interpretation is notably more reliable than that of a lay assessment of the injured diver in the field.

LIMITATIONS AND CHALLENGES

It is impossible, and would be utterly imprudent, to try to establish a physician-patient relationship between DAN's medical staff and a diver calling the hotline. Managing the diver's expectations regarding what DAN can do over the phone can sometimes be challenging. DAN does not admit patients to medical facilities, provide direct or indirect patient care, medical evaluation, diagnostic processes, and treatment decisions. There are no "DAN patients" because DAN does not provide direct patient care, rather consultation and advice. In some cases, a diver might infer that calling the DAN Hotline serves as a face-to-face professional medical evaluation. In those cases, the limitations of this type of interaction often need to be made explicit. An injured person can only become a patient when he/she is under the care of medical personnel. While still in the field, professional medical assistance starts with the medical personnel from the local emergency medical services (EMS) having jurisdiction.

DAN assists with diving emergencies from callers on the furthest and most remote corners of the world. It is not uncommon for dive teams operating in remote locations to include a recompression chamber, and enthusiastic and dedicated chamber operators and inside tenders. However, suboptimal or even non-existent medical supervision often leads to a telemedicine discussion where DAN is asked to assume this role. This is not a scenario we encourage or are comforatble with, but rather one where we play Good Samaritan.

Today's advancements in telecommunications technology have significantly bridged the gap between face-to-face interactions and video telecommunications. While there will always be limitations with this type of interaction, the main obstacle is often not operational but significant jurisdiction and medico legal. DAN works well in many remote areas by assisting non-dive-expert medical doctors and supporting recompression chambers with training, education, and immediate availability for consultations 24/7.

DAN accepts all incoming calls from members and non-members from anywhere globally. Although English is widely spoken in most tourist destinations, languages can sometimes be challenging. Some of these calls originate in remote locations. The technical quality of these telecommunications is often unpredictable, which contributes to the overall challenge of remotely assisting someone in distress remotely.

While DAN strives to provide injured divers and those caring for them with the best possible recommendations, telephonic communication imposes considerable limitations. Within reason, DAN must assume the worst-case scenario from a differential of possible injuries until the injured diver has been adequately assessed. Not all severe or life-threatening diver injuries involve complications from bubble formation and instead require emergent intervention that does not require recompression.

THE ROLE OF THE DAN EMERGENCY HOTLINE

DAN Medical Services Department hosts the DAN Emergency Hotline. One might compare this function to a poison control center, but in this case the expertise lies in diving injuries. DAN's Emergency Hotline service can support and complement local EMS services, but never assumes its role as first responders. The role of the DAN Emergency Hotline can be summarized in these five functions:

1.) To evaluate through a telephonic triage whether the reported symptoms might be the result of a diving injury.

The first step to the successful treatment of any disease is a correct diagnosis. The hotline agent will start by taking a detailed case history, including: the nature of the symptoms, dive history, chronology of events, and any past medical history that could be deemed relevant. The agent will recommend the best course of action based on the information relayed by the caller. When the caller is a layperson in the field, the reported symptoms must be carefully interpreted, as people often misuse medical terms. Obtaining input from others on board, especially those with medical training, is helpful in rapidly obtaining the necessary information.

2.) To guide the caller through first aid treatment of diving injuries.

One of DAN Hotline's most valuable contributions in managing scuba diving injuries is providing the lay caller with guidance on first aid treatment. Effective and efficient first-aid actions are vital in maximizing the efficacy of definitive treatment. Recommendations are often limited by external factors, including the availability of trained and medically proficient first-aid responders, adequate and sufficient first-aid equipment, and DAN's knowledge of the resources in that geographic region. In some areas, local dive medical resources are so readily available that the first-responders' role is minimal.

3.) To persuade the injured diver to seek professional medical evaluation.

Time, not distance, to the closest medical facility, is the most crucial element in turning an injured diver in the field into a patient within the local healthcare system. Geographic location will determine whether advanced medicine — including recompression therapy — is a realistic expectation within a reasonable timeframe.

4.) To advise the non-dive-expert medical professional on the diagnosis and management of diving injuries.

Once the injured diver becomes a patient within the local healthcare system, DAN's medical staff makes themselves available to aid a doctor who is unfamiliar with diving injuries in making the best possible decisions for their patient.

5.) To aid DAN members with evacuations to a suitable dive medicine facility.

The best dive destinations are often far from robust medical facilities. DAN maintains a database of active and competent recompression facilities worldwide to assist with diving injuries. When the injured diver is a DAN member, DAN can assist with the medical evacuation efforts to ensure our member receives the necessary treatments at the closest and most appropriate medical facility.

CALLS TO MSCC

One of the metrics we use to quantify the MSCC services is the number of interactions with customers contacting us through phone calls or emails for emergency medical and travel assistance and non-emergency medical information. An interaction includes any every contact of our medics with an external party.

We classify interactions into three main groups:

- **Cases**: Initial inbound contact for emergency medical and travel assistance, related or not to diving
- **Inquiries:** Initial inbound contact for non-emergency medical information, mostly related to travel and diving
- **Follow-ups:** Sequential inbound or outbound contacts for both emergency medical assistance or non-emergency medical information.

Of the 22,540 interactions in 2018, DAN recorded:

- 14% cases (3,127)
- 28% inquiries (6,373)
- 58% follow-ups (13,040)

Among the 6,373 inquiries, the leading topics were:

- Diving physician referrals — 1,574 (25%);

Diving physics and physiology information — 1,060 (17%).

The number of emergency cases over five years is shown in Table 2-1

YEAR	CASES	INQUIRIES	TOTAL
2014	3,169	6,361	9,530
2015	3,485	6,635	10,120
2016	3,593	6,727	10,320
2017	3,809	7,094	10,903
2018	3,127	6,373	9,500
Total	**17,183**	**33,190**	**50,373**

Table 2-1: Emergency cases and information requests per year.

In 2018, the total number of calls was 5.6% less than the average of the previous four years (2014–2017). The number of cases was down 10.4%, and the number of inquiries 5.6%. The total number of reported and acquired diving fatalities was reduced, which implies that perhaps the number of emergency and information requests might also go decrease to reduced diving. This affected calls from all geographic regions, but the decrease was most extensive in the U.S., Mexico, and the Caribbean, as shown in Figures 2-1 and 2-2.

The seasonality of emergency and information calls is shown in Figure 3-3. A higher call volume in the warmer months between May and August (when more diving is practiced) is unsurprising, given many calls originate from North America. Most reported cases were diving related, as shown in Table 2-2. The distribution of diving related cases according to a suspected health problem category is shown in Table 2-3. The type of symptoms in suspected decompression sickness (DCS)

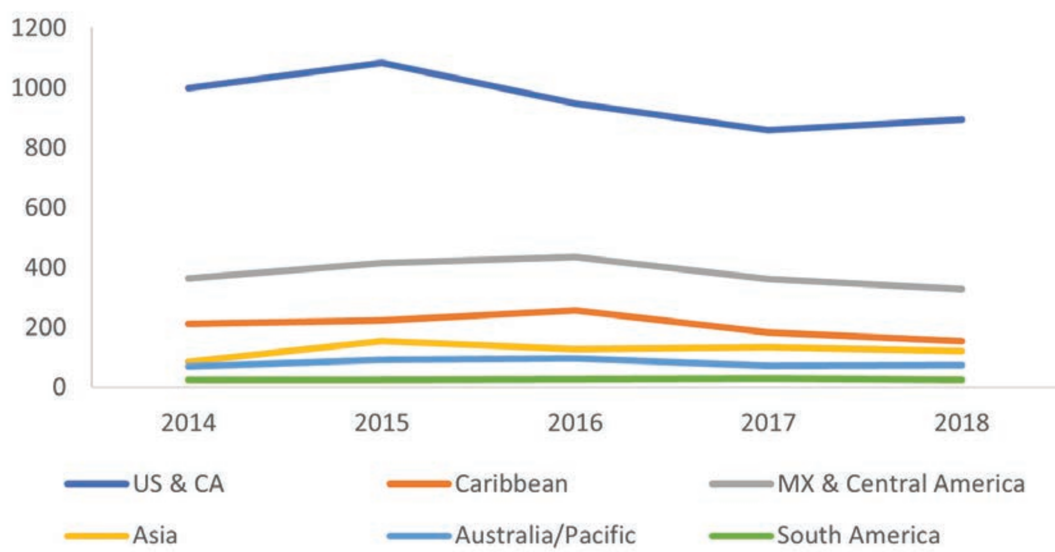


Figure 2-1. The geographic origin of emergency calls 2014–2018.

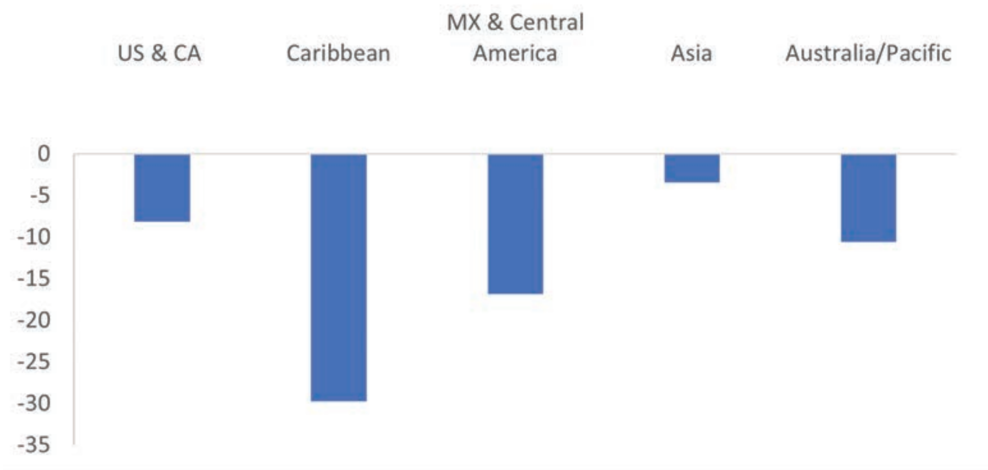


Figure 2-2. The percent change in the volume of emergency calls in comparison to average numbers in the 2014–2017 period.

cases as averaged over the past four years compared to 2018 is shown in Table 2-4. Figure 2-4 represents the percentage of DCS distribution by neurological, pain only, cutaneous, and pulmonary symptoms.

EVACUATIONS

Some severe injuries and cases in remote locations require evacuations. The geographic area and number of evacuations (by average) in 2018 are shown in Table 2-5. Many cases were evacuated on regular commercial flights (48). An air ambulance was used in 47 cases and a fast boat in two cases. Most evacuations were assisted by Travel Guard (88). In five cases, the evacuation was organized directly by DAN, and in four cases, it was self-arranged by the divers. The distribution of evacuations by the health problem and means of evacuation is shown in Table 2-6. The age of evacuees is shown below in Figure 2-6.

SELECTED 2018 CASES

DECOMPRESSION SICKNESS

MILD OR TYPE 1 DECOMPRESSION SICKNESS (DCS)

The term 'mild DCS' has been defined as a mild presentation not likely to result in long-term harm even without recompression.[2] Mild DCS typically includes single joint pain, red or marbled skin rash, activation of the lymphatic system such as swelling or lymph node involvement (the classic type 1 DCS nomenclature), and mild subjective neurologic symptoms like numbness and tingling. Transient, nonspecific symptoms, informally referred to as 'niggles', are marginal DCS manifestations and not included in the mild or type 1 designation.

Two critical requirements for the classification of mild DCS are normal neurological findings and no progression within 24 hours. Suspicion of either mild

ILLNESS/INJURY	2014 -2017 (mean)	2018 (count)	2018 (% of 2014–2017 average)
Diving Related	2,117	2,069	97.7
Non-Diving Related	1,502	1,395	92.9
Total	**3,619**	**3,464**	**95.7**
% Non-Diving	41.5	40.3	97.1

Table 2-2. Diving and non-diving related injuries reported to DAN in 2018 compared to the previous four-year average.

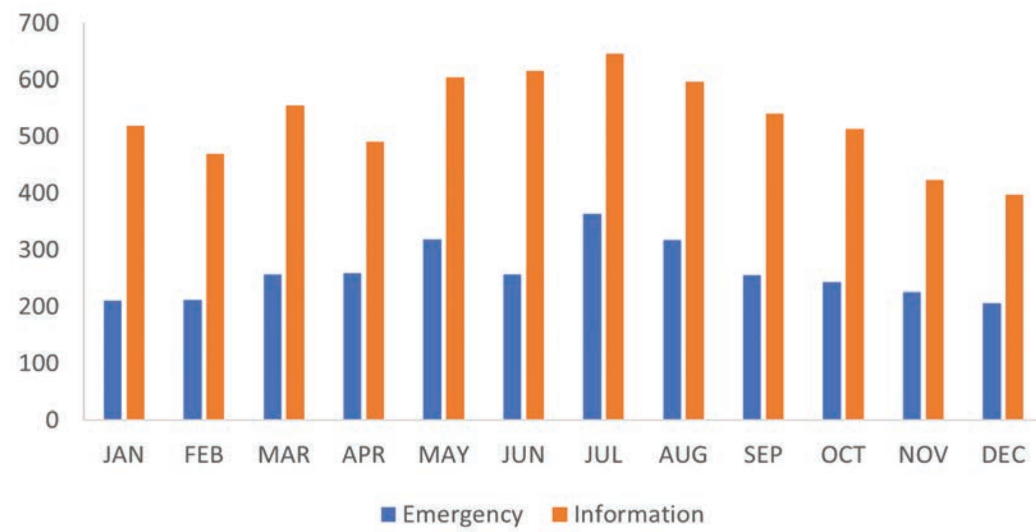
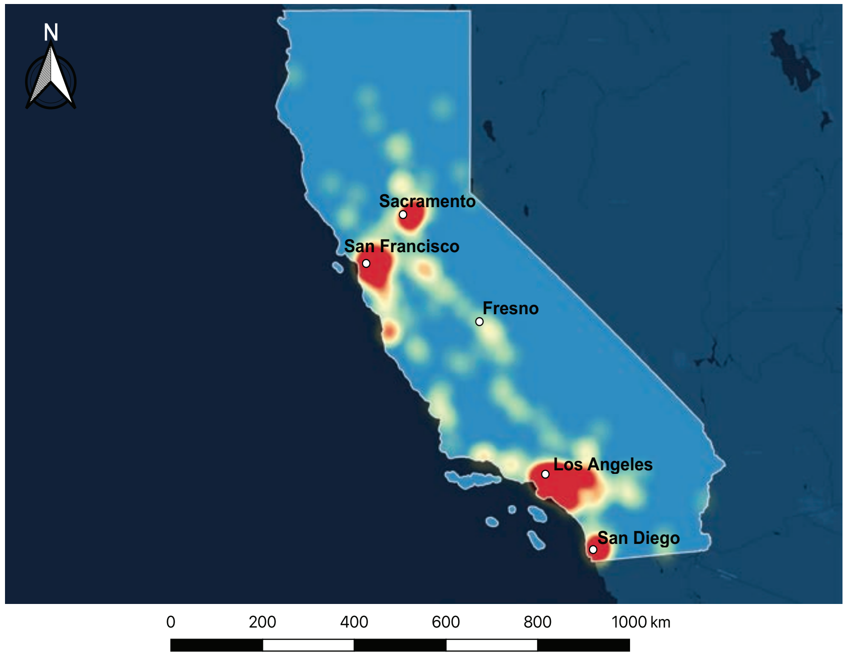


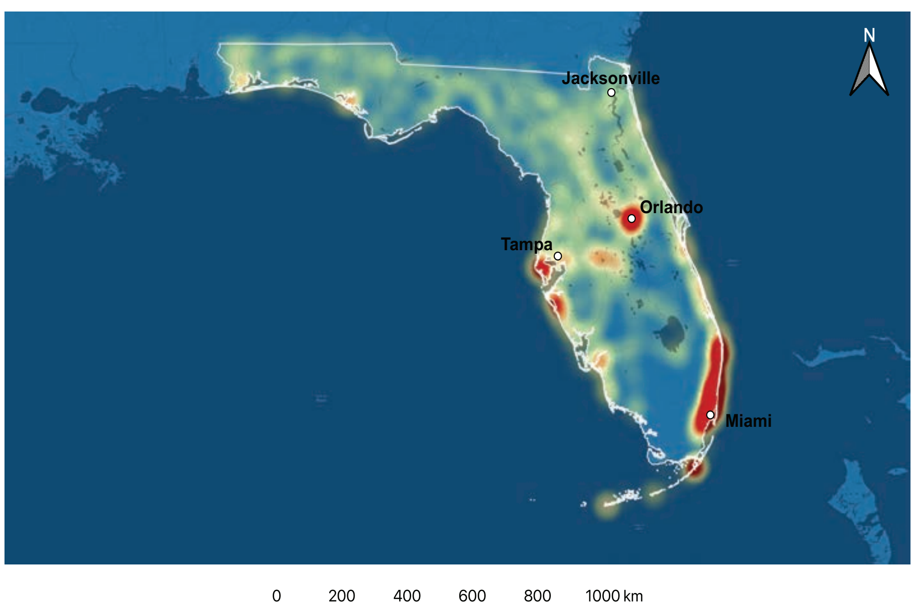
Figure 2-3. Seasonality of call volume: Count of emergency and information calls by month of the year in 2018.

DIVING RELATED	2014–2017 (mean)	2018 (count)	2018 (% of 2014–2017 mean)
Barotrauma	1,008	1,053	104
Decompression Sickness	606	624	103
Marine Envenomation	234	202	86
Immersion Pulmonary Edema (IPE)	46	47	102
Arterial Gas Embolism (AGE)	40	41	104
Fatality	41	18	44
Non-Fatal Drowning	23	17	76
Gas Contamination	22	18	84
Finfoot	18	13	71
Motion Sickness	14	24	171
Mask Squeeze	15	5	33
Loss of Consciousness	11	5	45
Cardiac Arrhythmia	7	0	0
Nitrogen Narcosis	3	2	62

Table 2-3. Diving and non-diving related injuries reported to DAN in 2018 compared to the previous four-year average.



Map 2-2: Volume of emergency calls from California in 2018.



Map 2-3: Volume of emergency calls from Florida in 2018.

DECOMPRESSION SICKNESS	2014–2017 (mean)	2018 (count)	2018 (% 2014–2017 average)
Neurological (DCS Type 2)	269.75	222	82.3
Cutaneous	158.75	141	88.8
Pain Only (DCS Type 1)	139.25	160	114.9
Pulmonary / Chokes	8.5	4	47.1

Table 2-4. Distribution of DCS cases by type of symptoms

Geographic Region	Air Ambulance	Commercial	Ground or Fast Boat	Grand Total
Africa	1			1
Aus/Oceania		1		1
Caribbean Basin	20	5		25
Central America	5	7		12
Europe		5		5
Mexico	2	13		15
Middle East		1		1
N America	2	8	1	11
Pacific	3	1		4
SE Asia	14	7	1	22
Total	**47**	**48**	**2**	**97**

Table 2-4. Evacuations in 2018.

or marginal DCS at onset does not imply the dive team should disregard or neglect the episode, but demands that emergency measures be taken. In addition, these mild symptoms may progress to more serious findings with serial neurologic examination. The distinction of mild vs serious DCS, which has important treatment implications, can be challenging by means of a telecommunication. Below are some illustrative cases.

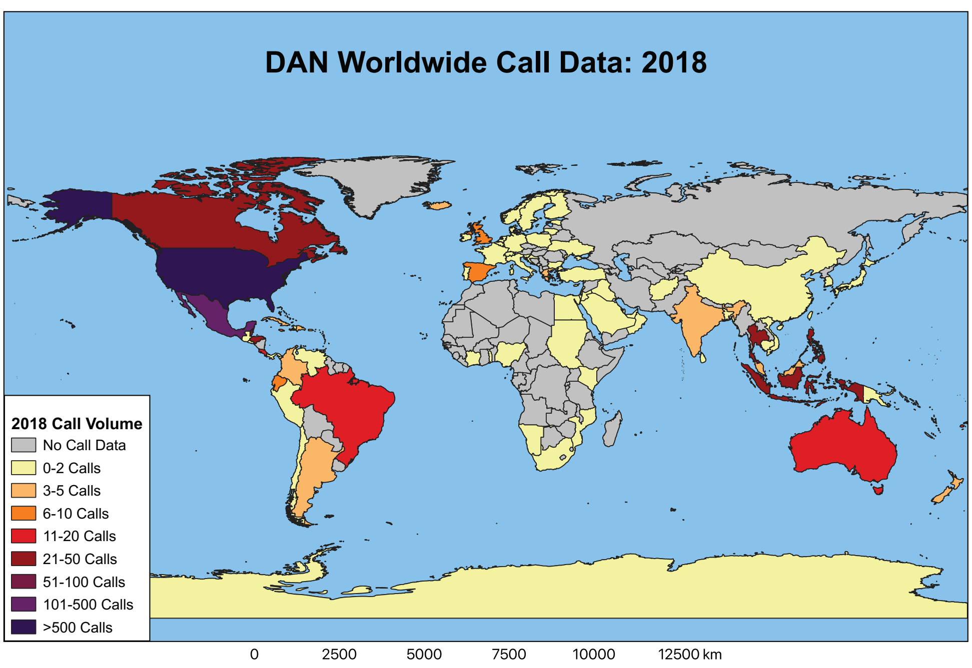
Deep shoulder pain with swelling, skin redness and a sense of tightness in the arm

A 63-year-old man performed two decompression trimix dives, the first to 53 meters (174 feet) for 58 minutes and the second to 46 meters (152 feet) for 46 minutes. About two to three hours after the last dive, he noticed moderate deep shoulder pain that radiated down his arm. It was also associated with swelling, skin redness, and a sense of tightness in the arm. No neurologic deficits were noted. He sought attention the following day and was recompressed. Within minutes after reaching treatment depth, he had substantial pain relief and complete relief several minutes later. The treatment was completed following the U.S. Navy Treatment Table 5 (USN TT5). At his follow-up appointment the next morning, he only had mild swelling. He was diagnosed with decompression sickness (DCS) type 1, musculoskeletal and lymphatic involvement with full recovery.

Commentary: *There was sufficient exposure to cause DCS in this case. The symptom onset time close to surfacing and joint pain in combination with skin swelling and redness were very indicative of DCS. With these manifestations, the case could be classified as mild. The diver was obviously not in much pain as he waited till the next day to seek help. Luckily, there was a hyperbaric center within his reach. He was evaluated and treated adequately without much delay and with a complete resolution except for the remaining mild swellingof the limb. Recompression has been shown to relieve the pain caused by lymphatic obstruction by bubbles, but it may take longer for the body to resorb the excess fluid*

Flying with cutaneous and lymphatic DCS

A 43-year-old man on a seven-day liveaboard trip was diving several times per day, with his average depths between 24–35 meters (80–115 feet). His last two dives were to 34 meters (111 feet) for 55 minutes and 25 meters (84 feet) for 43 minutes with little more than one-and-a-half-hour surface interval in between. During the trip, he took zero days off from diving. One hour after the last dive, he noticed swelling and itching on his chest



Map 2-4. Countires of origin of emergency calls. .

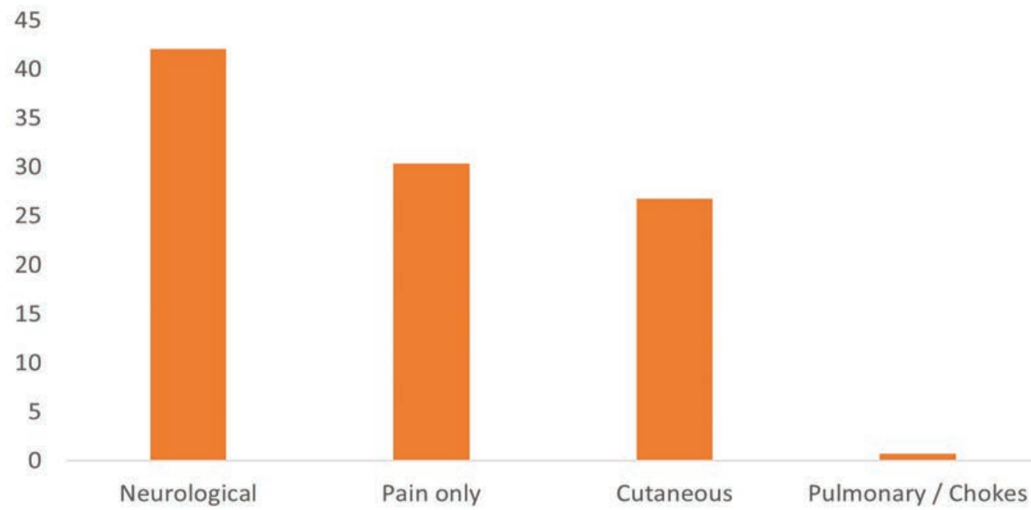


Figure 2-4 The distribution (%) of 2018 suspected decompression sickness (DCS) cases by type of symptoms.

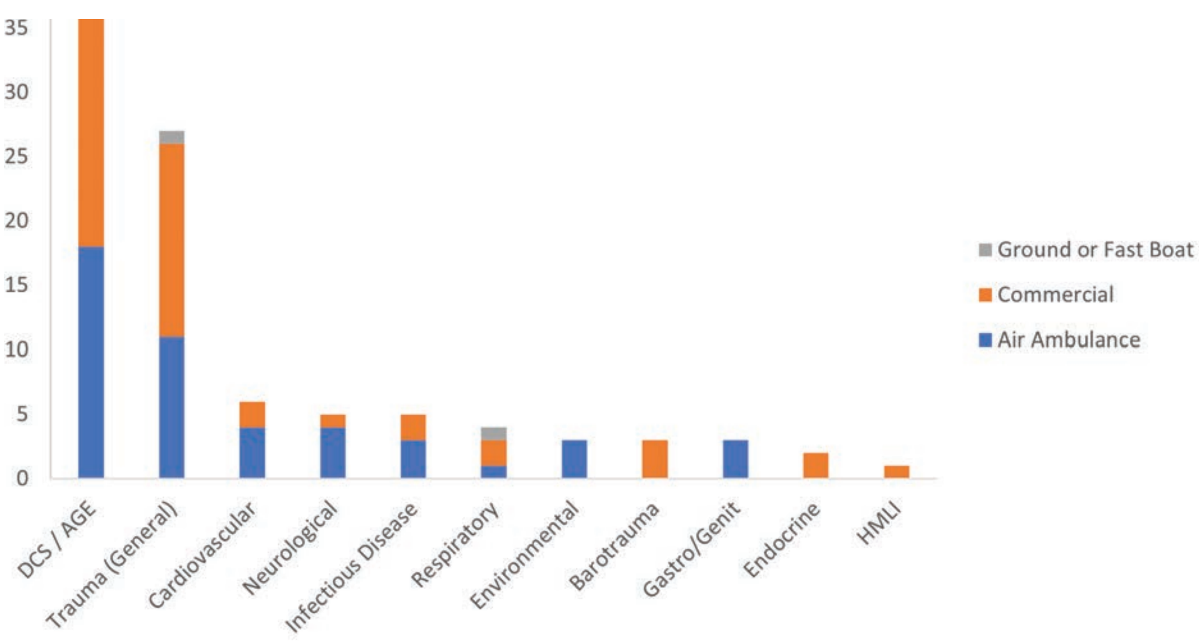


Figure 2-5. Number of evacuations by ground/boat, commercial and air broken down by health problem.
HMLI, Hazardous Marine Life Injuries.

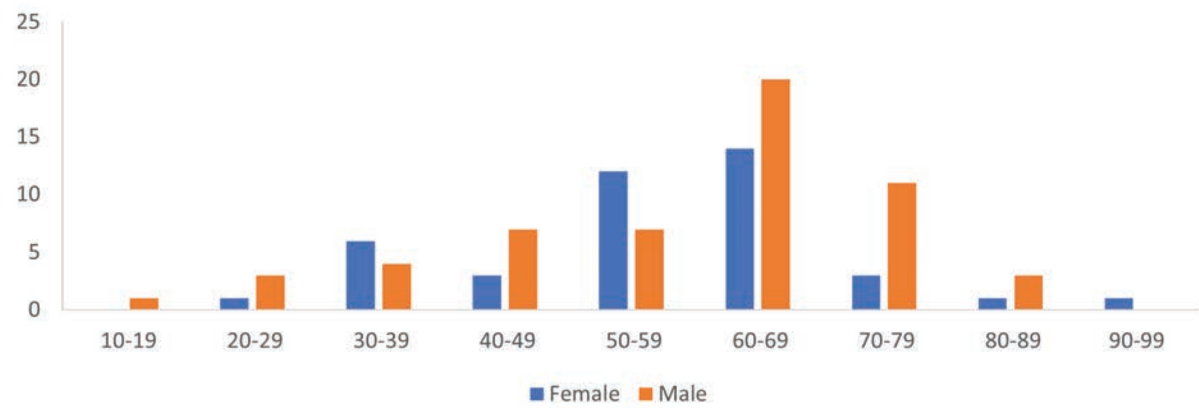


Figure 2-6. Number of evacuations due to dive related incident, broken down by gender and age.

and abdomen. He reported that his pectoral muscle on the one side looked like he had been working out while his abdominal swelling appeared like prominent “love handles.” The crew provided him with first aid normobaric oxygen. The boat did not pull in until the following day. He sought medical evaluation in a local medical unit and recommended that treatment was not necessary. He made a thousand mile plus trip home by commercial air without incident. He followed up with his physician after eight days. By that time the swelling had nearly resolved.

Commentary: *The question remains as to the risk of decreased ambient pressure following treatment and the waiting time before flying after recompression therapy. In this case, the diver with stable cutaneous and lymphatic manifestations of DCS flew without treatment and reported no change in his condition occurred during the flight of over three hours. Cutaneous manifestations may be associated with neurological symptoms that a diver may not be aware of, and it is strongly advised to seek medical evaluation before flying. The swelling of the skin may be only one of the manifestations of leaky capillaries, which may cause a loss of circulating plasma with a resulting decrease in blood pressure. In this case, the patient was stable, and the physician did not find a reason to keep him in the hospital. The case could be retrospectively classified as mild DCS, which resolved without treatment.*

Post dive shoulder pain confused for an old injury

A 33-year-old man conducted two dives to 18 meters (60 feet) for approximately 50 minutes each while collecting fossils. The dives were uneventful. During the night, a significant right shoulder pain woke him up. The pain persisted no matter how he changed positioning, and he tried over-the-counter pain medications with no relief. The diver had shoulder surgery several years ago, and at the local emergency room, he was discharged with a musculoskeletal diagnosis. However, he had not had any difficulties with previous dives or exercise. He called DAN, who directed him to a hospital with a recompression chamber. He was recompressed and got prompt relief of his shoulder pain in less than ten minutes at 18 meters (60 feet). A full U.S. Navy Treatment Table 6 (USN TT6) was given. He was asymptomatic during follow-up the next day.

Commentary: *Differentiating a musculoskeletal injury from decompression illness can be challenging. Evaluating previous injuries is critical. Getting a clear understanding of any pre-existing chronic pain, deficit, and location from previous injury or surgery is important. Most recreational diving is planned to be relatively atraumatic and without heavy workloads. However, performing a new activity such as spearfishing, collecting, and hauling gear by the normally sedentary can result in stressed strains in the common areas. The characteristics of the pain can provide some clues. Palpation of muscle, tendon, joint lines, etc. can assist in identifying some of these musculoskeletal injuries. In the absence of a clear connection to previous injury or no indication of strain during the dive, joint pain could be considered DCS and the diver should be recompressed. While hyperbaric oxygen may help with some soft tissue injuries and edema, prompt resolution of symptoms upon reaching the treatment depth, in this case, support the diagnosis of DCS.*

SEVERE OR TYPE 2 DECOMPRESSION SICKNESS (DCS)

Severe or Type 2 DCS comprises neurologic, otologic, and cardiopulmonary forms of decompression sickness. It may be progressive and affect vital functions. It is diagnosed by detailed history and physical examination that includes serial neurologic assessments. Once identified, referral for recompression therapy is usually indicated.

Partial loss of visual field during decompression from a deep dive

A 65-year-old male technical diver made a single-day, single dive to 59 meters (193 feet) for 60 minutes in a cold, freshwater environment. During his decompression, at around 18 meters (60 feet), he noticed that he could not see part of his computer display. After returning tothe dock, he called DAN, where he reported feeling fine otherwise. When inquired about specifics of the loss of his visual field, he said that when he got to the surface, the visual loss became less severe, but when looking at someone's face, he could "not see their nose or the upper right part of their face." He denied any history of visual problems. He did not have any other symptoms and was not aware of any other medical problems. He was reportedly able to walk normally, had no problems with basic coordination tasks, no pain, no sensory changes, and no history of altered consciousness level since symptom onset. At all times, he appeared calm and very articulate. He was referred to a nearby medical center with a hyperbaric complex and extensive dive medicine experience. It was recommended that he start first aid with oxygen while en route. At admission, about ninety minutes later, the reported symptoms were still present. The patient was recompressed to 18 meters (60 feet) in a hyperbaric chamber. Within ten minutes, he had a full resolution of symptoms. The treatment was completed on the US Navy treatment table 6. A follow-up call the following day revealed that the diver was still asymptomatic. He was discharged with recommendations to follow up with a dive medicine specialist.

Commentary: *A loss of visual field is a rare event in diving. It may be caused by DCS or AGE affecting the eye, optic nerve, or brain. Ocular decompression sickness is very rare and it manifests with blind spots. It is not easy to decipher what type of change in the field of vision the diver was experiencing. He could have a scotoma — changes in the retina of the eye (caused by ocular DCS) — or a quadrantanopia — changes in the parts of the optic nerve or even brain cortex (known as DCS of the brain). However, the acute loss of the visual field may be due to various other causes with a far more concerning prognosis than DCS, and medical evaluation at an appropriate medical facility is advised.*

TYPE 3 DCS: COMBINED DCS AND ARTERIAL GAS EMBOLISM

Arterial gas embolism (AGE) is a severe diving injury. Its severity may be increased if previous dives have caused loading of the body with inert gas. The bubble emboli that are forced into the vasculature from lung barotrauma — or a paradoxical embolism — can obstruct or reduce the circulation to vital tissues. Time sensitive off gassing by the tissues requires unrestricted bloodflow. Also, these original gas bubble emboli that have lodged in vessels may receive additional inert gas from the surrounding tissue and grow, further impeding the resolution of those same bubbles. This severe combination of gas embolization with a significant inert gas load has been called type 3 DCS.

Possible AGE case

A diver in his 30s was making his fifth dive of the day to depths between 21–24 meters (70–90 feet), over 35 miles offshore. Upon a final rapid ascent from his decompression stop he was reportedly acting erratically. Upon reaching the surface he complained of visual disturbance and right-sided weakness. His speech was garbled, and conversation confused. His vision improved shortly after being offered oxygen. He was flown ashore by the coast guard to a medical facility where he received recompression therapy.

Commentary: *His rapid ascent and immediate onset of these symptoms are consistent with AGE. One must also consider he conducted 5 dives to 90 fsw that day and therefore inert gas loading of the tissues causing cerebral DCS might also be the sole or contributing cause of his symptoms.*

Inner Ear DCS vs. Inner Ear Barotrauma vs. AGE

A 49-year-old male diver, complaining of a sudden onset of severe loss of balance 15 minutes after surfacing from a single dive to 22 meters (75 feet) with a total dive time of 25 minutes on air. The diver denied any equalization problems during the dive, had no ear pain, pressure, or fullness in his ears. He could not walk without assistance, as this made him feel very vertiginous and nauseated. The diver had a friend coming to take him to the hospital for evaluation. The agent on-call agreed this seemed to be the best course of action and encouraged the diver to have the emergency room physicians contact DAN after evaluation. When following up with the diver he stated he had been diagnosed with inner ear decompression sickness (IEDCS), and that he received a U.S. Navy Treatment Table 6 (USN TT6), that same night, after which he felt some "significant improvement." A second treatment the next morning (presumably a U.S. Navy Treatment Table 9) reportedly "did not help much". The diver said he was then discharged, albeit still being

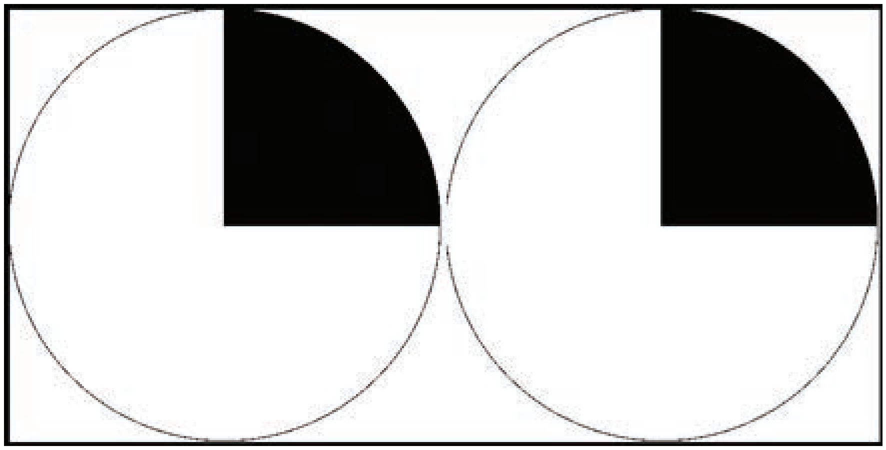


Figure 2-7. Right superior quadrantanopia. The areas of the visual field lost in each eye are shown as black areas. This visual field defect is characteristic of damage to MEyer's loop (part of optic radiation) on the left side of the brain.

dizzy enough having to ask someone to drive him. DAN recommended following up with his primary care physician to determine whether it was worth consulting with an ear-nose-and-throat specialist for possible inner-ear barotrauma (IEBT).

Commentary: *Classic literature describes IEDCS as usually being the result of aggressive decompressions, significant decompression stress, gas switching during mixed gas diving, and deeper exposures. While these types of exposures can cause IEDCS, it seems likely that IEDCS can also happen with less significant decompressive insults. Symptom onset is usually minutes to hours after surfacing, although it can also be present in the course of staged decompression during aggressive diving. On the other hand, IEBT is typically the result of inadequate or failed middle-ear equalizations. Symptom onset is typically immediately after a sudden change in barometric pressure, like vertical travel or forceful equalization techniques.*

Differential diagnosis between IEDCS and IEBT is one of the most challenging dilemmas for a dive medicine physician. Both conditions can present with similar clinical manifestations but have radically different treatment approaches. Treatment for IEDCS involves recompression therapy, which in the case of IEBT, could cause further harm if the patient has ear equalization problems. However, in a case of doubt, recompression is usually the right choice provided any difficulties with equalization can be addressed properly. The dive exposure was reportedly moderate, and response to treatment seemingly marginal, one could argue that a case of IEBT would have also improved somewhat over the same period with or without recompression therapy. In DAN's experience, half of the cases of IEBT do not seem to have a clear association with provocative maneuvers that could trigger a barotraumatic injury of the ear. The critical element in the differential diagnosis is a thorough anamnesis.

AGE could also explain such a sudden onset of acute focal neurological deficit. Provocative maneuvers like climbing up a fully geared ladder or lifting heavy equipment, may open a right-to-left shunt. When in the presence of venous gas emboli, shortly after surfacing for example, this can lead to a paradoxical embolism.

Shoulder pain and swelling while spearfishing after a series of six successive deep dives

A 37-year-old man called the DAN hotline the day after completing six spearfishing dives at 43 meters (140 feet). He complained about right shoulder pain, which occurred initially after his second dive. He continued diving, as the pain would go away on descent to 9–12 meters (30–40 feet) only to return on ascent at around 5 meters (15 feet) and remain during the 45–60 minutes surface intervals. The pain was significant enough that after the fifth dive, the diver considered not going on the sixth dive but was convinced by his dive buddy to do it. After the sixth dive, he had pain in both his shoulders. The pain and pressure worsened overnight and the next morning he felt like his joints were "going to explode." He also said his shoulders appeared significantly swollen. Upon DAN advice, the diver was admitted to a local emergency room. The evaluation showed no neurological abnormalities, and the patient was referred to a nearby hospital with a hyperbaric center. The diver reported no significant improvement duringa standard U.S. Navy Treatment Table 6 (USN TT6). The swelling was almost entirely resolved the following day, and his pain had reduced significantly. A second treatment continued to improve his symptoms. He was discharged after the third treatment on the third day after symptom onset.

Commentary: *This case illustrates a clear case of musculoskeletal DCS with a lymphatic component. Despite the aggressive dive history and four subsequent exposures after symptom onset, the diver did not present any neurological abnormalities during the evaluation. The response to recompression was not immediate, but it is not uncommon for the swelling from lymphatic involvement to take days to fully resolve with or without additional recompression treatments for that spontaneous resolution.*

The paralytic form of DCS after a 600ft dive

A 57-year-old male called before his second hyperbaric treatment, a day after his diving incident on a small island among the Greater Antilles, located in the Caribbean. The diver self-reported to be an expert rebreather diver, usually diving to 121–152 meters (400–500 feet) at depth. On this occasion, he completed three dives in three days. On day one he did a 121-meter (400 feet) dive, on the second day he completed a no-DECO dive to 24 meters (80 feet) dive, and on the third day, the diver made a 185-meter (609 feet) dive for what he says was "zero bottom time." When asked to clarify, he explained they descended quickly to 27 meters (90 feet) and then straight down a wall where the last 30 meters (100 feet) were sloped instead of vertical, and he had to work hard to stay off the bottom. He estimated that the time from initial descent to start of the ascent to be about 10–15 minutes. He was using a rebreather with the partial pressure of oxygen set to 1.2 ATA. His breathing gas was 5/80. During the ascent, at around 21 meters (70 feet), he realized his right leg was paralyzed. He dropped back to 33 meters (110 feet) and symptoms resolved. To avoid recurrence of these symptoms, he decided to add an hour to his decompression obligation, which made his total dive time three hours. His decompression gas was his rebreather with a set point of 1.2 ATA.

A few minutes after surfacing, he noted tingling in his legs and difficulty walking. He went home, took three aspirin and breathed oxygen for an hour. When he realized he had urinated without awareness, he decided to go to the local hospital. Upon arrival at the local emergency room, he noted his gait was wobbly. The diver received one treatment in a monoplace chamber to 3 ATA for 2.5 hours. Breathing gas was oxygen, with five-minute air breaks every 30 minutes.

His reason for calling DAN was to make sure we had been contacted, as he was a member. At the time of the call, he complained of numbness in his right leg up to the ankle and in his left leg up to the hip. He said he could move part of his right foot but could not move the leg or lift it. Before his treatment, he could not feel his feet, but that had resolved. He had a urinary catheter in place and was expecting an ambulance to pick him up in 30 minutes for another chamber treatment. Working together, allowed for possible evacuation plans so that the diver could receive a higher-level of care, to be arranged. The treating physician was contacted via phone the next day. The doctor said the patient was reporting improvement from a complete paralysis at admission to 60 percent of normal muscular strength, and the paresthesia was reducing in intensity and area. He also said they were planning to continue with another short treatment that morning, after which they would reevaluate. If deemed necessary, they were open to a second treatment that same afternoon. Later that day, the patient reported his balance had improved, and could now walk without assistance. The patient received three treatments, with the first reportedly being a U.S. Navy Treatment Table 5 (USN TT5), and the following two shorter ones. He continued to improve, recovering 80 percent of his muscular strength after the third treatment and was starting to feel the urinary catheter. The patient flew commercially on the fourth day, with no relapse of symptoms during the flight, and continued rehabilitation at his hometown in Southern Florida. A year later, the diver called back, informing he had returned to diving. He still suffers constipation, and when he dives, he has incontinence. He called to ask about ways to manage these residual symptoms.

Commentary: *This case depicts how extreme dives can sometimes go wrong, and how short treatments in monoplace units can have surprising success. The occurrence of paralysis during ascent indicates severe decompression stress from a deep dive. While the standard treatment protocol in case of severe decompression sickness (DCS) is recompression following the U.S. Navy Treatment Table 6 (USN TT6), immediate treatment with a suboptimal treatment table is better than optimal treatment days later. In this case, the diver was in a remote location and the local chamber was reportedly not capable of administering the USN TT6. However, instead of waiting for an air ambulance, which would have taken at least 24 hours, the diver was treated at his local hospital. In the first 36 hours post dive this diver received three recompression treatments and achieved a significant functional recovery. Compromised bladder and bowel function always indicates spinal cord involvment, and residual symptoms are likely even with optimal treatment and under the best circumstances.*

CUTANEOUS DCS

Divers that miss the more subtle neurological symptoms are likely to notice the more obvious cutaneous manifestations. Although cutaneous manifestations can appear impressive in severe DCI cases, in the absence of any other manifestations, a delayed onset of 'skin bends' a few hours following a dive is usually considered a mild form of DCS. Skin bends may present as mild swelling, itchiness and/or red rash areas. Early recognitions of these symptoms should prompt divers to stop diving and seek medical evaluation. We present more cases summaries involving cutaneous manifestations to help divers to recognize this condition. The skin can be pruritic and present as:

- raised red rash
- peau d'orange; rough, dimpled appearance that resembles the peel of an orange
- cutis marmorata; bruised or marbled skin

Cutaneous manifestations require full neurological examination. Even if neurological findings are normal, careful observation with serial neurologic examinations is recommended to avoid missing progression to more serious DCS manifestations, particularly when there was an early onset following a dive.

Extensive abdominal skin mottling and itching after a single day of recreational dives

A 38-year-old woman, otherwise healthy, with two years of diving experience, did two consecutive and uneventful morning recreational dives in a single day. The second dive was to a depth of 26 meters (85 feet) for a total dive time of 40 minutes. Three hours after the end of the second dive, she noticed a red, flat, discolored, and itchy bruise on her right abdomen and side. No other signs and symptoms were reported. Given her recent diving history DCS could not be excluded. She was asked to take photos of her skin and send them to DAN. Figure 2-8 illustrates typical cutaneous DCS. She was recommended to seek medical evaluation and was then provided directions to a local medical facility. At the local emergency room her condition was interpreted as an allergic reaction. She received a corticosteroid injection and was discharged. The next morning, her skin changes were still present and she had some difficulty walking, possibly due to pain at the steroid's injection site. She went to a local hospital with a hyperbaric chamber, but was unable to see a hyperbaric medicine specialist for her symptoms. She commented on this to her instructor who recommended she breathe oxygen, which provided great results within the hour (Figure 2-9). She was finally seen by a diving medicine specialist who cleared her to fly back home.

Commentary: *Cutaneous manifestations of decompression sickness are often misdiagnosed as allergic reactions or bruises, particularly on busy emergency rooms whose staff that is unfamiliar with diving medicine. When persuading a diver to seek medical evaluation, DAN always recommends that they have the examining physician call for consultation; however, this doesn't always happen on time.*

Abdominal left-sided skin blotching

A 22-year-old healthy female diver who completed eight uneventful recreational dives in two days of liveaboard diving, with maximum depths of 29 meters (95 feet). Eight hours after the end of the last dive, she noticed a rash on her belly (Figure 2-10). The liveaboard crew considered the rash to be skin DCS and she completed a course of oxygen breathing during the two-hour navigation to the closest medical facility. At the facility, the DCS diagnosis was confirmed and she started treatment with one U.S. Navy Treatment Table 6 (USN TT6), on the first day and one U.S. Navy Treatment Table 5 on the following day. After the second treatment she was discharged without any symptoms and flew home without issue six days post-treatment. Once home she followed-up with a trained dive medicine physician for a fitness-to-return-to-dive evaluation.

Commentary: *This was a good response by the diver bringing her symptoms to the attention of her dive supervisor who administered first aid; prompt evacuation to a medical facility allowed the diagnosis and referral for appropriate recompression.*

Extensive abdominal skin marbling in a male diver, fully resolved after single delayed recompression treatment.

The diver was a 58-year-old healthy male who completed twelve uneventful recreational dives in five consecutive days. The diver stated he noticed some minor itching to his abdomen when waking from a nap after his first dive on the last day (Figure 2-11). The diver applied Cortisone® cream, and the itchiness seemed to resolve. The diver completed a second dive that day and noticed a rash to the belly two hours post-dive. The diver described the rash as reddish/purplish, splotchy and itchy (Figure 2-12). The diver thought that maybe he was reacting to the cleaning solution used to clean his dive gear. The diver stated he flew home on the following day; no additional symptoms were reported. The initial call to DAN was made on day three after the last dive. He was informed that the onset, description, location and pictures were all very consistent with skin decompression sickness. In addition, he reported weight gain, abdominal girth and breast swelling, which were probably a result of lymphatic involvement. He was provided information for a local medical facility and recommended to go immediately and call back for follow-up. At the hospital,

Figure 2-8 (left). Suspected cutaneous DCS onset three hours after the second dive.
Figure 2-9 (right). Same individual one hour after oxygen treatment at local dive shop.

the diagnosis was confirmed, and he started treatment with one U.S. Navy Treatment Table 6 (USN TT6), in a monoplace chamber on the fourth day after diving. He experienced 100-percent resolution and was discharged with general recommendations for being medically cleared to return-to-diving.

Commentary: *Misdiagnosing cutaneous DCS as an allergic reaction is very a very common occurrence. The characteristic rash following an aggressive series of dives associated with swelling from probable lymphatic involvement (and weight gain) is often DCS. The need for prompt evaluation is important. It is even more so if flying home and experiencing the decrease in barometric pressure that may worsen the condition.*

Right arm swelling and skin mottling after a single 100 feet decompressive cave dive.

A 57-year-old healthy female, with no history of previous decompression sickness, called DAN two hours following a dive to report a possible development of skin bends in her right bicep (Figures 2-13 and 2-14). The dive profile was 30 meters (100 feet) of freshwater for 92 min, with decompression stops of four minutes at 12 meters (40 feet), eight minutes at 6 meters (20 feet), 12 min at 3 meters (10 feet) with oxygen breathing for the whole ascent. She reported mottled skin accompanied with pain. She breathed oxygen for an hour, hydrated, and eventually felt better. The arm remained swollen for some time after treatment and the skin remained blotchy but not itchy. Other symptoms slowly resolved over time. DAN advised that cellulitis may be another possible differential diagnosis, but with this dive profile it was likely to be lymphatic DCS. She received a recommendation to seek immediate medical attention. At the hospital emergency department cellulitis and deep vein thrombosis were ruled out with appropriate evaluation and she was transferred to the care of the hyperbaric unit. At the hyperbaric unit, she was diagnosed with possible DCS and received a U.S. Navy Treatment Table 6 (USN TT6). After the recompression treatment, swelling lessened, she was discharged without symptoms and given the recommendation to postpone her flight back home for at least 24 hours after the end of the treatment. In addition, she was instructed to refrain from diving for a week.

Recurrent migraine with aura, breast pain, and skin mottling during and after three-weeks diving

A 32-year-old female had been diving almost daily for the past three weeks with a maximum diving depth of 24 meters (80 feet). She reported a migraine with an aura earlier in the week but denied any past medical history of migraines. She also reported having some transient pain around a breast after a dive two days prior. Her last dive was 24 meters (78 feet) for 75 minutes on 32.1 percent nitrox. The diver reported the onset of the migraine about two to three hours after surfacing. She also noticed that the skin on her right thigh was painful and had a marbled rash (figure 2-15). The diver intiated surface-level oxygen therapy at a local dive shop. She remained on oxygen for over an hour with some decrease in the pain experienced on her skin, but no other changes were noted with oxygen

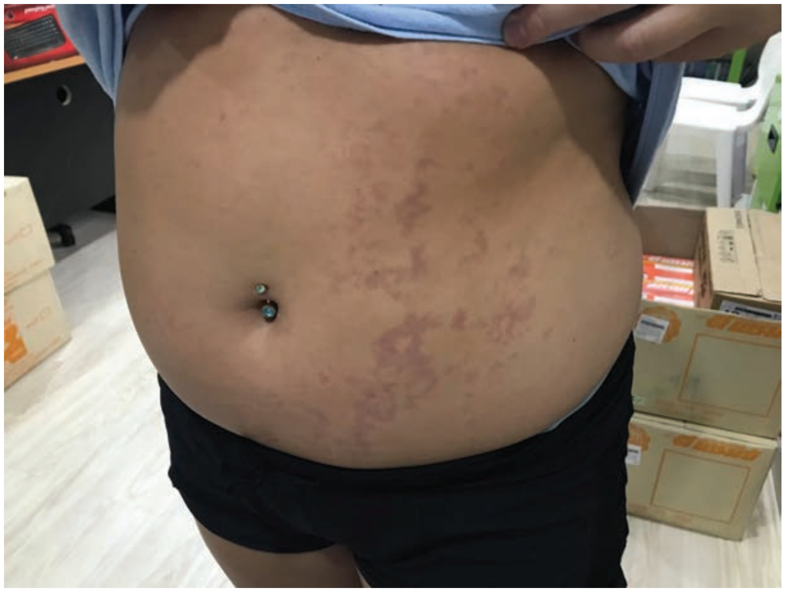


Figure 2-10. Suspected cutaneous DCS onset 8 hours after the end of the last dive..

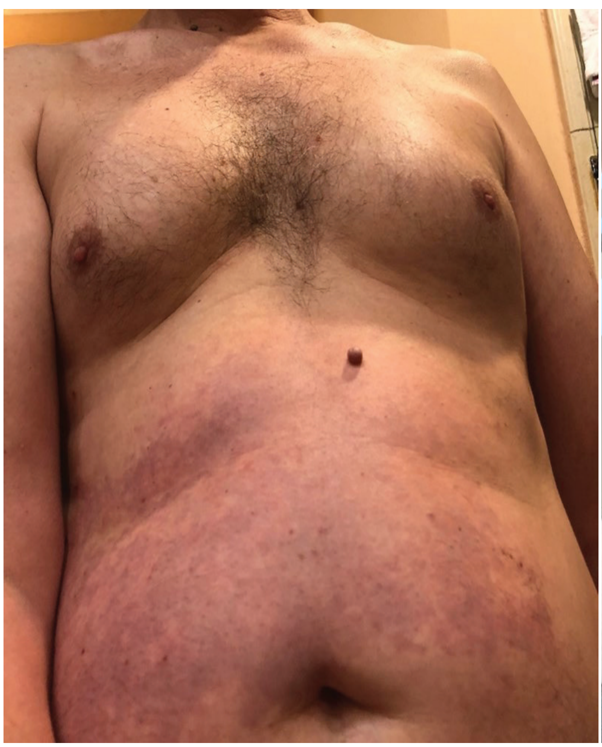



Figure 2-11 (left).Picture of rash described by diver on the last day of diving. Figure 2-12 (right). Reddish/purplish rash provided by diver. Rash presented two hours after the second dive of the day.

Figure 2-13. Suspected skin bends in right bicep

Figure 2-14. Suspected skin bends in right bicep

Figure 2-15. Marbled rash on right thigh.

breathing. The diver refused medical evaluation and saw a gradual improvement in her symptoms over time. Two days after the dive, she reported that the marbled rash had subsided. She had no headaches, but she noticed she had "pinprick sensations" in her fingers and feet. It is unknown if the diver returned to diving.

Commentary: *When there is an indication or suspicion of DCS, aborting any further diving, initiation of first aid and proceeding to the nearest medical facility are indicated. A new headache with aura and skin rash indicative of DCS further emphasized the need for evaluation. Her extensive diving without a break certainly may explain her episode of DCS. Her symptoms could be a possible reason for obtaining a bubble contrast echo to rule out a patent formen ovale or PFO. Her persistent symptoms may preclude her from diving for an extended period of time.*

Hip pain, abdominal pain and rash

An emergency call was received from a dive guide requesting assistance. The guide informed DAN medicine that she had a diver, a 52-year-old female, who had been diving three dives per day for 12 of the past 14 days. The diver's last day of diving involved three dives consisting of one to 22 meters (72 feet) for 70 minutes with a surface interval of just over a minute. Her second dive was to 20 meters (65 feet) for 60 minutes with a surface interval of merely three minutes. Her last dive of the day was to 16 meters (55 feet) for 70 minutes. All her dives were on 32 percent nitrox. About two hours after her last dive, the diver reported right hip pain that progressed to the left hip and then to the abdomen (Figure 2-16). She reported to the dive guide of these symptoms about six hours after symptom onset. At that time, the guide noted an abdominal rash consistent with previous cutaneous DCS cases they had seen. The diver was started on surface-level oxygen therapy via a non-rebreather mask at the dive center medical station. She remained on oxygen for over an hour with improvement in the rash and with a resolution of her hip pain. A doctor was not available when the guide was alerted about the symptoms, but a call was made to DAN medicine.

The DAN medic agreed that the description and pictures were consistent with cutaneous decompression sickness, but a diagnosis could not be given over the phone. A nurse was present at the dive center and reported a normal neurological test along with a diver report of hip pain resolution and rash improvement (Figure 2-17). The following day, a physician saw the diver and reported that the diver had been on normobaric oxygen for over four hours. All pain had resolved, but the diver still had some residual skin rash. The treating physician reported a normal neurological exam and no other symptoms.

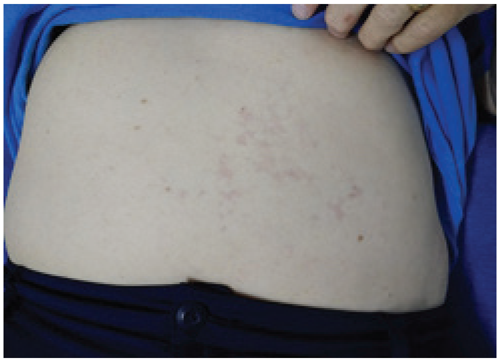


Figure 2-16. Suspected cutaneous DCS presenting approximately two hours after last dive.

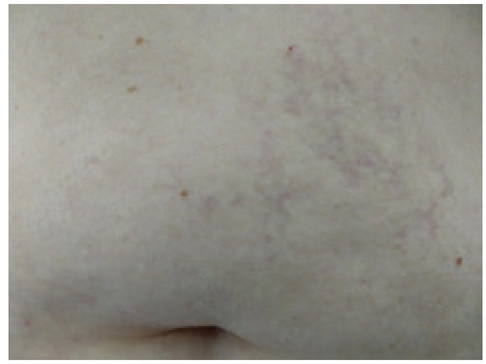


Figure 2-17. Suspected cutaneous DCS, rash improvement

Commentary: *Extended periods of repetitive diving can increase the risk of DCS. It is unknown where she had taken her two days off during these 14 days of diving. An additional degree of safety may be obtained by using air tables for decompression especially for multi day repetitive diving. Additional conservatism is recommended when diving in remote locations without adequate recompression facilities.*

Diver with serious DCS and cutaneous manifestations requiring multiple hyperbaric treatments

An email notification was received from a hyperbaric chamber manager regarding a diver that was brought to the facility. The diver, a 41-year-old male, had been on four dives over the previous two days breathing air. His first dive was to 21 meters (70 feet) for 50 minutes and a second, 47-minute dive to 20 meters (65 feet). The next day included a 50-minute dive to 21 meters (70 feet), followed by a dive to 18 meters (60 feet) for 40 minutes. The surface interval time between each of the dives is unknown. The diver did not report any symptoms prior to diving, no difficulty equalizing during the dives, denies any rapid ascents, and no omitted decompression stops.

After surfacing, the diver went to a restaurant where he became ill. He began having blurry vision, nausea, and vertigo. He went to the bathroom and had an episode of vomiting and defecation, then lost strength in his right arm. He asked his wife to take him to the hospital, but a stranger in the restaurant took the diver straight to the hyperbaric facility where he was placed on oxygen therapy. The treating physician found the diver to be pale with dry mucus membranes and needed assistance to walk. Dizziness prevented the diver from walking in a straight line or able to touch his finger to his nose. Nausea prevented him from sitting upright for the exam. Pupils were equal and reactive to light with noted nystagmus (repetitive, uncontrolled horizontal movements of the eyes). There was also a decrease in strength in the right arm.

The treating physician diagnosed DCS and prescribed recompression therapy. Four hours after surfacing, the diver received his first U.S. Navy Treatment Table 6 (USN TT6). After treatment, the diver showed improvement in symptoms. He complained of fatigue and dizziness but was able to walk without assistance and continued to have some numbness to his right arm. His pallor resolved, but a rash appeared on his lower back. He was sent back to his hotel to rest and return the following day for a follow-up. By next morning, the rash was still present in addition to fatigue and slight dizziness.

Due to the persistence of symptoms, the treating physician prescribed an additional treatment table 9 with complete symptom resolution. During the next day follow-up, the treating physician noted normal findings on all body systems and discharged the diver from his care.

Recurrent epigastric pain with marbled warm and swollen skin over abdomen and chest

An email notification was received from a hyperbaric chamber manager regarding a diver that was brought to the facility. The 54-year-old female diver completed five dives in two days, breathing air. The first day included a dive to 28 meters (93 feet) for 41 minutes, a second dive to 21 meters (70 feet) for 49 minutes and a third dive to 8 meters (27 feet) for 49 minutes. The next day included a dive to 28 meters (92 feet) for 53 minutes, followed by a dive to 18 meters (63 feet) for 56 minutes. The surface interval time between each of the dives is unknown. The diver did not report any symptoms prior to diving, no difficulty equalizing during the dives, denies any rapid ascents, and included decompression stops.

Upon completion of her second dive on the first day, she noted pain in her abdomen, but it resolved with rest. She then completed the third dive. The abdominal pain returned after the third dive, but she did not attribute it to the dive and the pain later resolved. The next morning, she was noted to be asymptomatic and completed two dives, with the pain returning after the second dive, along with nausea and a rash that covered her midsection and chest. With the returning and new symptoms, she believed that the symptoms could be secondary to the dive. She went to a local chamber for medical attention, but there was no physician on call, so she was referred to the treatment department located within the same facility.

The treating physician found the diver to be stable. The marbled rash was noted on her chest and abdomen, and her abdomen was warm and swollen. All other systems appeared normal on the initial exam. The treating physician immediately diagnosed this diver with DCS and prescribed hyperbaric treatment. The diver received U.S. Navy Treatment Table 6 (USN TT6) and after one treatment, symptoms were improved. She had no more nausea, the pain in her abdomen and chest were much improved, and the rash had faded significantly. She was sent back to the hotel to rest and return for follow up the next morning. The following morning, the diver's abdomen was still warm and distended, her chest was painful to touch, but the rash had mostly faded away; just dull vestiges of the rash remained. The treating physician noted normal findings on all other body systems and discharged the diver from his care.

CARDIOPULMONARY DCS (CHOKES)

One of the most severe forms of decompression illness (DCI) are 'chokes' or cardiopulmonary DCS, which manifests as a massive build-up of bubbles that overwhelm the vascular system causing cardiovascular collapse and can lead to death. Fortunately, its occurrence is not as common to the other forms of DCS. Dives with large decompression obligations that are omitted or significantly shortened often contribute to the development of cardiopulmonary DCS. Survival is dependent on maintaining effective circulation despite the massive bubble accumulation in the central vasculature. Prompt recompression is the most effective therapy. First aid measures include normobaric oxygen, fluids, and lying in the prone position. Obstruction by the bubbles may interfere with off gassing from super saturated tissues and result in other forms of DCS that may be overlooked, especially if the dramatic effects of the chokes partially resolve. In addition, intravascular replenishment is vital as considerable fluid loss occurs as a result of the damage to the endothelial integrity and subsequent leakage into the surrounding tissues. Below we describe some cases that occurred during this period.

Harvesters with multiple long deep dives experience initial DCS symptoms before reaching the surface

Two divers in their 30's completed repetative dives on air across successive days to 38 meters (125 feet) for 30–40 minutes. During these dives they were harvesting on the bottom. On their last dive of the day, they began to have trouble breathing during ascent and needed help boarding the vessel. Despite weakness, they chose in-water recompression to 9 meters (30 feet). One of the divers became unresponsive at depth during the procedure and was brought back to the surface by his buddy. They were both taken to a medical facility while breathing surface oxygen. Both complained of shortness of breath and chest tightness. The one diver who was unresponsive in-water, demonstrated evidence of pulmonary aspiration and bilateral edema. Both were experiencing abdominal pain and numbness in their lower extremities. They were both evacuated to a recompression chamber where they received recompression using an extended U.S. Navy Treatment Table 6 (USN TT6) and subsequent follow-up treatments.

Commentary: *Multi day, repetitive deep air dives can increase the risk of serious DCS. Dives such as harvesting where most of the time is spent at the maximum depth before direct ascent to the surface may carry an additional risk. Allowing for a longer surface interval, skipping a dive day or use of nitrox may help mitigate that risk. These divers experienced spinal and cardio-pulmonary DCS. The use of in-water recompression has been used by the well prepared. Ill-prepared, incapacitated divers serving as each other's tenders is not a recommended scenario for in-water recompression. As feared, one of the divers did lose consciousness. Fortunately, they were recovered and suffered a non-fatal drowning with complications before receiving his definitive recompression in a hyperbaric chamber.*

An experienced diver conducting repetitive deco dives experiences symptoms shortly upon surfacing

A diver in his fifties made two decompression dives to 24 meters (80 feet) and 27 meters (90 feet) using air with bottom times well over one hour and with a one-hour surface interval. The diver claims to have completed any decompression obligations. Shortly after reaching the surface, he noted chest pain and shortness of breath. This was followed by an altered level of consciousness and marbling of his skin. The diver became dizzy which improved when he lay supine. He was given oxygen with some degree of relief of his symptoms, and was transported to a medical facility, stabilized with 3–4 liters of saline, and prescribed recompression therapy with complete relief of his symptoms.

Commentary: *This is a case of serious DCS with cardiopulmonary manifestations associated with cutaneous*

DCS. It is important to note that substantial volumes of crystalloid may be required to resuscitate divers with serious DCS while transporting to the recompression chamber.

Cardiopulmonary DCS associated with cutaneous manifestations after long shallow dive

A woman in her 30s made multiple decompression dives for several days without any problems. The day before her incident, she locked into a shallow water habitat constructed for her and others to reside in overnight. She surfaced and left without any evaluation or period of observation. Shortly afterwards she presented with difficulty breathing, coughing, and chest pain. This was followed by a bruising and a rash over her shoulder and abdomen. She was taken to the emergency room where she received oxygen, fluids, and was then transported to a recompression chamber where she was treated.

Commentary: *Multiple decompression dives for several repetitive days can pose an increased risk for decompression illness. Saturation diving and habitat operations normally discourage any diving prior to such diving. Leaving without a period of observation after the dive could have had a bad outcome. This woman fortunately did not end up a fatality, which might have been the case had she not been transported and promptly recompressed.*

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SECTION 3. INTERNATIONAL DATA

John Lippmann, Alessandro Marroni, Marta Marrocco, Yasushi Kojima, Akiko Kojima, Dinesh Ariyadewa, Catherine Harris

INTRODUCTION

In an ideal world, all recreational diving fatality and injury data would be compiled in one worldwide database. However, while our goal, this is a challenging feat. We currently obtain data by making individual queries to diving safety counterparts internationally. For this report, we received contributions from DAN Asia-Pacific, DAN Europe, DAN Japan, DAN Southern Africa, and the Royal Cayman Islands Police Services (RCIPS). Data from the New Zealand Underwater Association's publicly available 2019 Annual Report was also reviewed.

DAN EUROPE

DAN Europe maintains a database of injuries and deaths that involve their members only. Data is collected via calls to their medical hotline and insurance claims. In 2018, a total of 1,979 diving-related emergency cases were reported — 461 cases were related to suspected or confirmed DCI. The number of DCI-related cases by type is presented in Table 3-1. Dive related fatality data for 2018 was previously published in the 2019 DAN Annual Diving Report.

DAN SOUTHERN AFRICA

According to DAN South Africa's 2018 database records, which contains both member and non-member queries, no diving-related deaths were reported.

OTHER AGENCIES

In the New Zealand Underwater Association's 2019 Annual Report, the Police National Dive Squad reported eight diving-related fatalities in 2018 and 86 total fatalities since 2006. In line with US trends, the report highlights the increasing numbers of divers with contradicting medical conditions and risk concerns for the aging diver population.

The RCIPS reported 14 deaths that occurred during snorkeling (n=13) or scuba diving (n=1). Of the snorkeling-related deaths, 11 were male (average age 68 years, range 47 to 83 years) and two were females (age 66 and 47 years); all were American nationality. The scuba diving death was a 66-year-old male from England. No other information was obtained.

DAN EUROPE HOTLINE AND CLAIMS REPORT

DCI Type	Confirmed	Suspected
Skin	107	21
Neuro sensorial	69	41
Neuro motor	44	12
Vestibular	45	12
Pain only	25	18
Cerebral	3	2
Pulmonary	5	0
AGE	4	0
CAGE	2	0
Taravana*	1	0
Unknown	24	26
Total	**329**	**132**

Table 3-1. Number of DCI Cases in DAN Europe members by type.Reported both by hotline and by membership claims. *Note: Taravana is a disease most commonly found amongst divers who descend and ascend in rapid succession, multiple times per day, to erratic depths and without breathing apparatus.

Table 3-2 displays the different diagnoses reported to DAN Europe in 2018. These reports were collected by both the hotline and through membership claims.

The following tables display the number of diving and non-diving accidents reported to DAN Europe based on country where the accident occurred. These reports were collected by both the hotline and through membership claims. The legend for these tables is as follows:

Over 200 accidents per year
Over 100 accidents per year
Over 70 accidents per year
Over 30 accidents per year

Diagnosis	2018
DCI	329
Suspected DCI	132
Ear barotrauma	152
Ear susp-barotrauma	52
Ear infection	100
Diving trauma - dry	44
Diving trauma - wet	83
Pulmonary susp-barotrauma	4
Pulmonary barotrauma	13
Pulmonary-emdema	11
Other barotrauma (dental/sinus/mask)	26
Other susp-barotrauma (dental/sinus/mask)	11
Marine-life-injury	38
Near-misses	13
Other diving	69
Diving death	22
Total	**1099**
Unknown	24
Total	329

Table 3-2. Diving related medical emergencies, 2018.

(A-D) Country of Accidents	2018
Albania	2
Andorra	
Argentina	
Aruba	
Australia	19
Austria	14
Bahamas	10
Belgium	30
Belize	6
Bermuda	
Bolivia	1
Bonaire, Sint Eustatius and Saba	10
Brazil	3
British Virgin Islands	1
Bulgaria	4
Burma (Myanmar)	
Cambodia	5
Canada	4
Cape Verde Island	4
Cayman Islands	6
Chile	2
China	
Cocos Islands	1
Colombia	5
Costa Rica	7
Croatia	33
Cuba	5
Curacao	4
Cyprus	28
Czech Republic	1
Denmark	1
Djibouti	1
Dominica	
Dominican Republic	21

(E-K) Country of Accidents	2018
East Timor	1
Ecuador	4
Egypt	195
Estonia	
Ethiopia	1
Faeroe Islands	1
Fiji Islands	9
Finland	26
France	38
French Polynesia	10
Georgia	1
Germany	27
Gibraltar	1
Greece	22
Grenada	1
Guadeloupe	3
Guam	1
Guatemala	1
Guernsey	
Haiti	
Honduras	7
Hong Kong	3
Hungary	
Iceland	1
India	2
Indonesia	235
Iran	1
Ireland	2
Israel	6
Italy	241
Jamaica	1
Japan	3
Jordan	1
Kenya	
Kuwait	1

(L-P) Country of Accidents	2018
Laos	2
Latvia	1
Lebanon	1
Lithuania	
Luxembourg	1
Madagascar	17
Malawi	1
Malaysia	14
Maldives	99
Malta	26
Marshall Islands	
Martinique	3
Mauritius	8
Mayotte Island	1
Mexico	79
Micronesia	4
Montenegro	
Morocco	1
Mozambique	5
Myanmar (Burma)	1
Nepal	1
Netherlands	7
Netherlands Antilles	8
New Caledonia	2
New Zealand	3
Nicaragua	
Niue	
Norway	4
Oman	3
Palau	3
Panama	3
Papua New Guinea	1
Peru	
Philippines	88
Poland	6
Portugal	13

(R-V) Country of Accidents	2018
Reunion Island	1
Romania	1
Russia	
Saint Martin	1
Saudi Arabia	7
Senegal	
Serbia	
Seychelles	3
Singapore	5
Slovakia	1
Slovenia	2
Solomon Islands	2
South Africa	4
South Korea	
Spain	104
Sri Lanka	8
Sudan	3
Swaziland	1
Sweden	6
Switzerland	18
Taiwan	
Tanzania	12
Thailand	268
Tunisia	1
Turkey	5
Turks & Caicos	2
Uganda	
Ukraine	2
United Arab Emirates	7
United Kingdom	8
United States	18
Vanuatu	
Venezuela	1
Vietnam	5
NO INFO	3
Total	**1979**

DIVING ACCIDENTS IN AUSTRALIA

John Lippman

THE DIVING EMERGENCY SERVICE

The Australian Diver Emergency Service (DES) has operated since 1983, initially from the School of Underwater Medicine in Sydney. From 1986 it has been based at the Hyperbaric Unit at the Royal Adelaide Hospital in South Australia. DAN Asia-Pacific has proudly sponsored the hotline from 1995 to 2018.

Until early 2019, calls to the hotline were answered by paramedics from the South Australian Ambulance Service and then transferred to an on-call hyperbaric doctor. For most of the years of operation, the doctors were based at the Royal Adelaide Hospital though in the final years, doctors from other Australian hyperbaric units also assisted.

In early 2019, with the introduction of DAN World into the region, the DES was wound up and the hotline diverted to DAN World. Calls are now taken by a DAN medic in New Zealand or diverted to the general DAN hotline in the USA, depending on the timing.

There were 331 calls received by the DES in 2018, as shown in Table 3-4. The remainder of the calls came from a variety of countries both within and beyond the Asia- Pacific region. Of the 331 calls, 111 (34%) were diagnosed as decompression illness (DCI) or possible DCI. thirty-six (11%) were diagnosed as ear or sinus problems, and five as marine envenomation.

The main signs and symptoms reported were pain (135), paresthesia (77), dizziness/vertigo (49), headache (46), skin rash (42), nausea (42), unusual fatigue (31), and weakness/paralysis (12). Eighty (24%) of the injured divers were reported to have received oxygen first aid, although near-100% oxygen was being provided in less than one quarter of these. Many thanks to Steve Goble for compiling the DES data.

Country	Frequency
Australia	128
Indonesia	68
Philippines	27
Fiji	11
Singapore	7
Thailand	7
PNG	10
Malaysia	10
Solomon Islands	8
Vanuatu	7
Hong Kong	3

Table 3-4. Origin of emergency calls to the Australian DES / DAN hotline

DIVING FATALITY REPORTING IN AUSTRALIA

Accurate information on the number, type and details of diving fatalities in Australia is generally not available for several years after the deaths until the coronial processes are completed. In the interim period, we rely on intermittent reports via the media and diving public.

The Australasian Diving Safety Foundation (ADSF) actively collects information on diving deaths and currently, it has reports on a total of 19 diving-related deaths in 2018.

Fourteen of these involved snorkelers or breath-hold divers, one was using surface-supplied breathing apparatus, and four were scuba divers (one using a rebreather). All of the scuba divers were males, with a mean age of 53 years.

DECOMPRESSION ILLNESS TREATMENTS IN AUSTRALIA

During 2018, a total of 100 divers were treated for DCI in Australia between eight hyperbaric units. The number of divers treated in each State/Territory are shown in Table 3-5. The total number of divers treated from 2012 to 2019 are shown in Figure 3-1.

Accident and fatality cases related to water sports including recreational scuba diving have been collected and the statistics are published by the Japan Coast Guard (JCG) every year. With these published data and those of collected by DAN JAPAN, recreational scuba diving fatalities in 2018 were analyzed. In this report, the word “fatality” includes those missing following a diving incident.

State	Treated
QLD	42
TAS	16
VIC	15
NSW	14
WA	12
SA	1
NT	0

Table 3-5. Divers treated for DCI in Australia in 2018

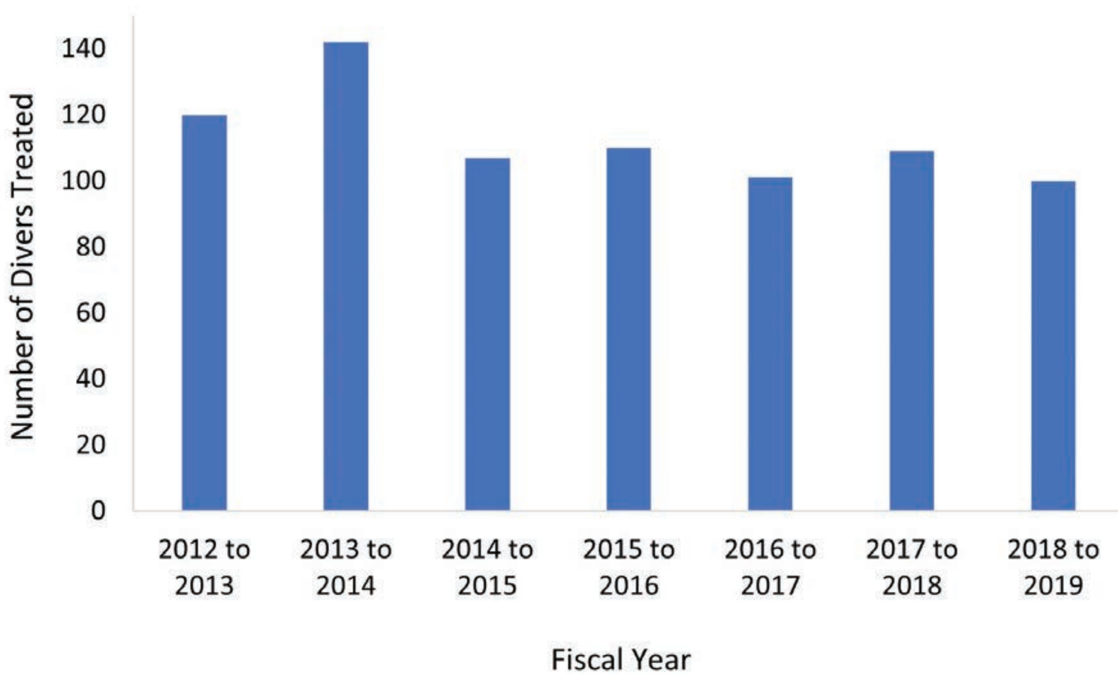


Figure 3-1. Divers treated for DCI in Australia, 2012 – 2019

RECREATIONAL SCUBA DIVING FATALITIES IN JAPAN

DAN Japan

GENERAL TENDENCY

Data from the last ten years (2009–2018) are illustrated in Figure 3-2, which shows total of seventeen fatalities (10 male and 7 female) including two missing in 2018, with 15.3 fatalities per year (red line). The black line shows percentage of male fatalities percentage (58.8% in 2018) and the ten-year-average was 66.7% (right axis.) The trend line indicates that the male fatality rate has gradually decreased in recent ten years.

The Japanese diving population can be between 300,000 and 500,000. Based on these figures, the fatality rate per 100,000 divers in 2018 is estimated to be around 3.4 to 5.6.

AGE GROUP DISTRIBUTION

Figure 3-3 shows the number of fatalities by age group. Of seventeen fatalities, nine cases were in their 50's and accounted for 52.9% of all fatalities. With the addition of the over 60 age group, the fatality rate increased as high as 64.7%. This tendency was also shown in 2017 data, where the fatality rate for over 50 years old divers was 56.3%.

The age distribution data of divers at a popular dive site in Izu peninsula from 2004–2010, divers in their 50's account for only 7.9% and over 50 years old divers were only 10.5% of all participants who enjoyed diving in this site.

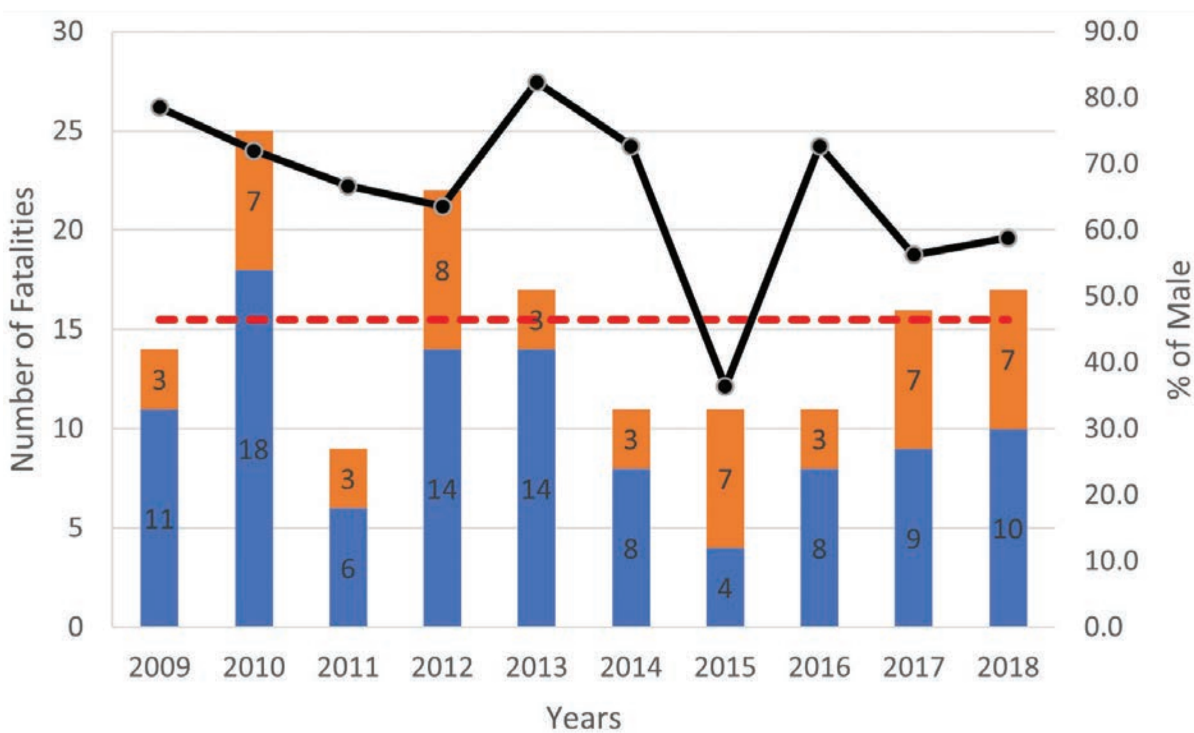


Figure 3-2. Number of fatalities from 2009 to 2018 reported to DAN Japan.

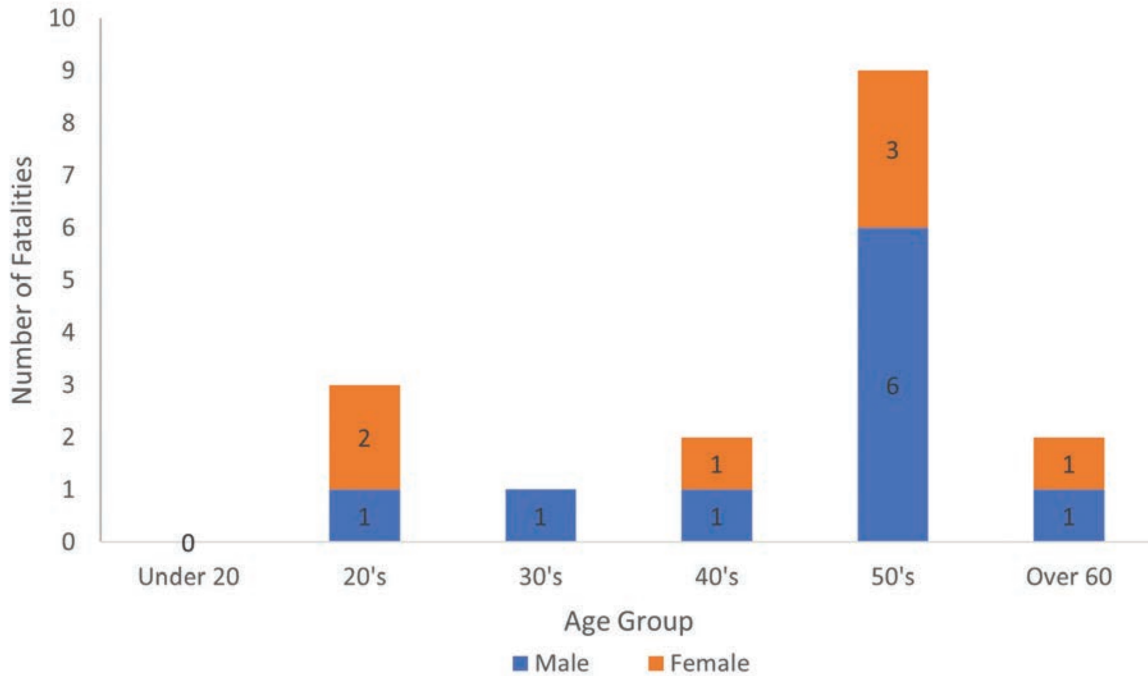


Figure 3-3. Number of fatalaties by age group reported to DAN Japan.

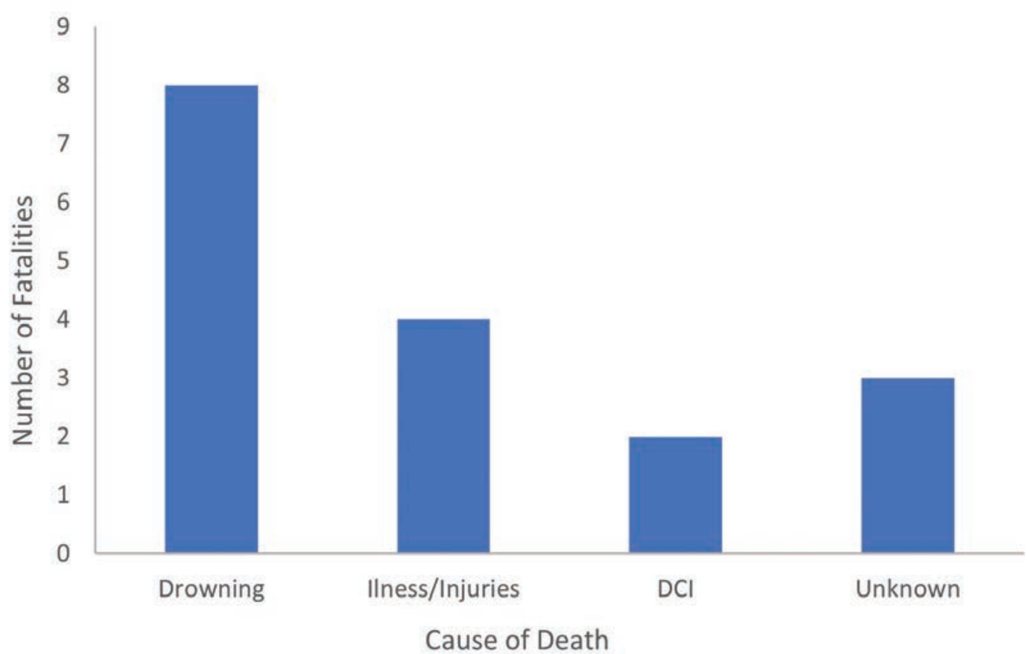


Figure 3-4. Cause of death reported to DAN Japan.

Considering these two figures; the fatalities rate and participants rate of over 50's, the fatality rate of these age group was apparently very high. It is suggested that aged divers are likely to have lifestyle-related comorbidities, for example, cardiac disease or stroke, hypertension, and/or high cholesterol.

CAUSE OF DEATH

The cause of death diagnosed by physicians are shown in Figure 3-4. Four cases of Illness/Injuries included sudden disease, acute heart failure, a myocardial infraction and multiple organ failure due to hypoxemia. Unknown includes two missing.

In eight cases of drowning, six cases or 75%, were over 40 years old divers and in four illness/ injuries cases, three cases, also 75%, were over 50 divers. This fact might also support the assumption that some hidden diseases in aged divers could trigger off the fatal accidents.

DIVER EXPERIENCE

The varying levels of dive experience held by divers invovled in fatal accidents are shown from different view point in Figure 3-5 and Figure 3-7. The former shows the years of experience and the latter, the number of dives experienced by the divers. On consideration of these data, it was suggested that dive experience itself could not guarantee dive safety, as fatalities occurred across the range of experience. However, a special attention should be taken to the number of fatalities in less experienced divers.

These figures illustrate the fact that the input of the diving instructor to educate divers correctly, and thus reduce the risk of fatalities is very important. Instructors must pay more attention to preparing, organizing and conducting these activities in accordance with the dive training standards.

Figure 3-6 illustrates the number of dives each diver made one year prior to the accident. The value was unknown the six cases (35.3%), while fatalities of those who did not dive past one year were as many as 5 cases or 29.4%,. Of these five, three cases were the accident during dive training (17.6%). These figures suggest that divers who dive regularly could be safer than those who did not.

FATALITIES BY MONTH AND DIVE TYPE

Fatal accidents occurred throughout the year, 35.3% cases occurred during summer season (June-August) and 23.5% occurred during autumn (September-November), these two seasons are high diving period in Japan. In winter (December-February), it had 17.6% while in Spring (March-May), 23.5% of reported fatal accidents.
Dive activities in Japan are usually executed with dive leader(s) who organize and lead their underwater dive tours. As the consequence, guided dive activities with instructor(s) and/or dive guide(s), such as Dive Master or Assistant Instructor had the most numerous fatalities as 41.2%, while in solo diving and entry training or experience diving, both had same three (3) cases resulting 17.6%. Group or buddy dive activities hold relatively smaller part, but had as high as 23.5%.

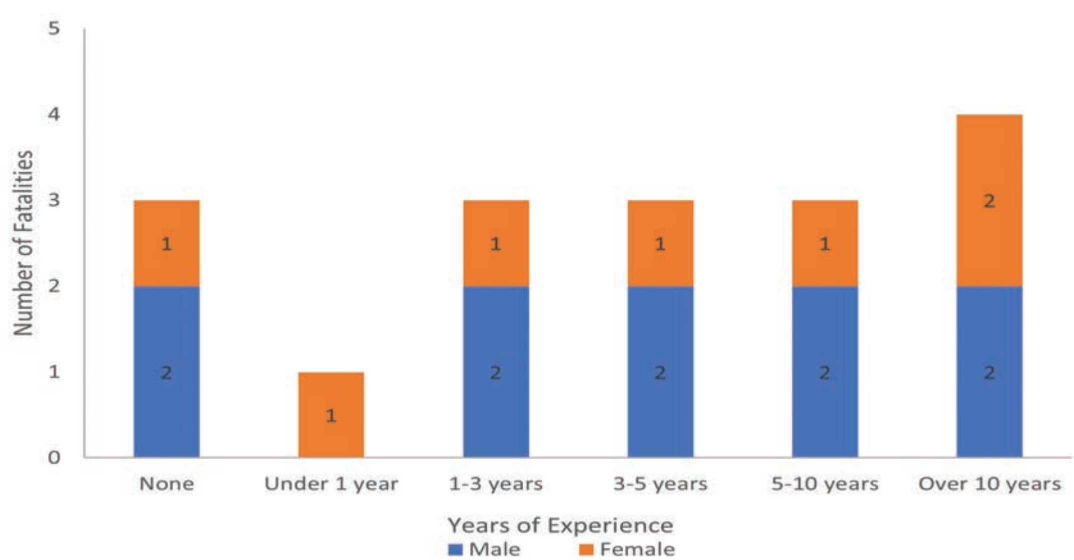


Figure 3-5. Number of fatalities by diver experience reported to DAN Japan.

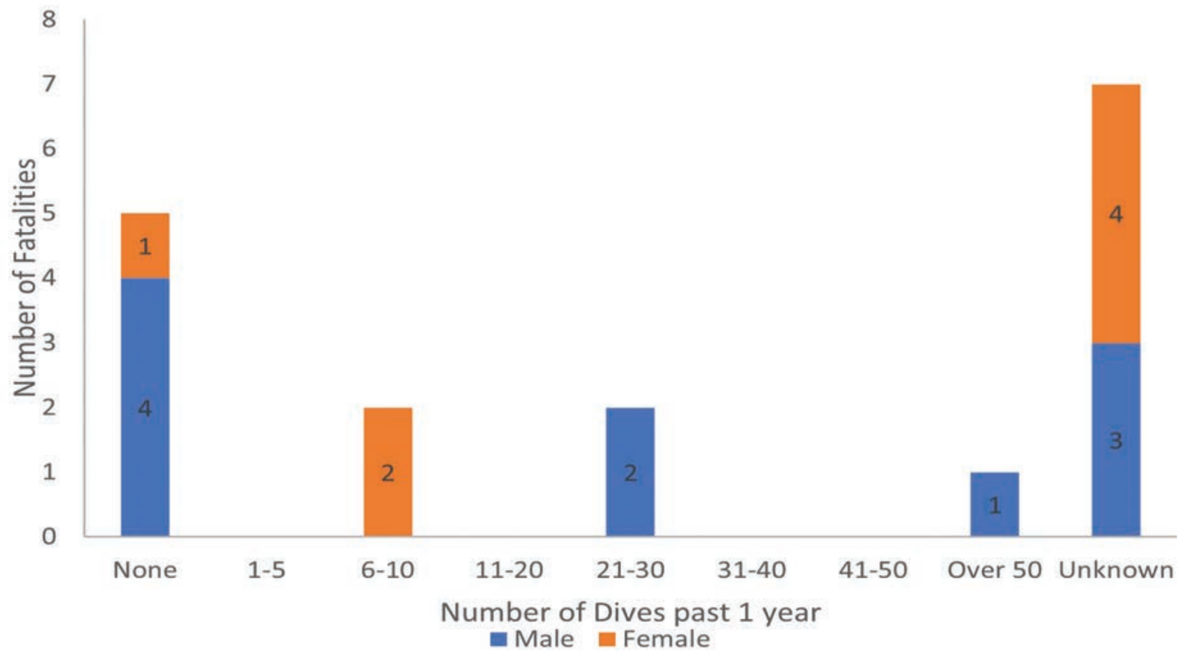


Figure 3-6. Number of fatalities based on number of dives completed one year prior.

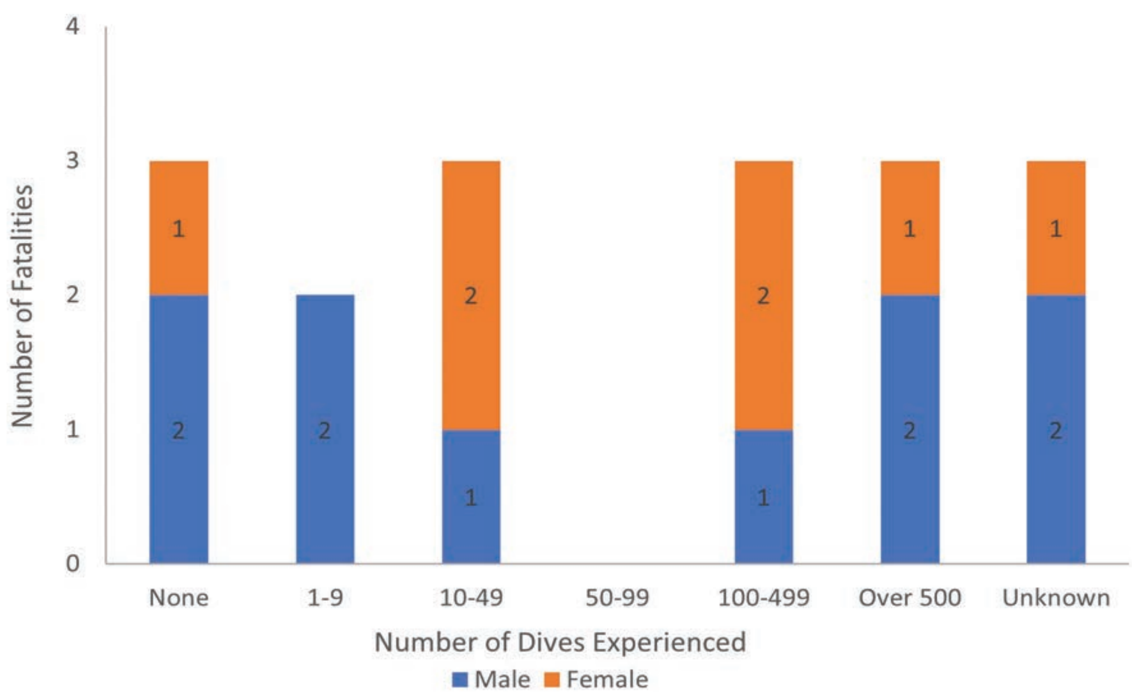


Figure 3-7. Number of fatalities by total number of lifetime dives.

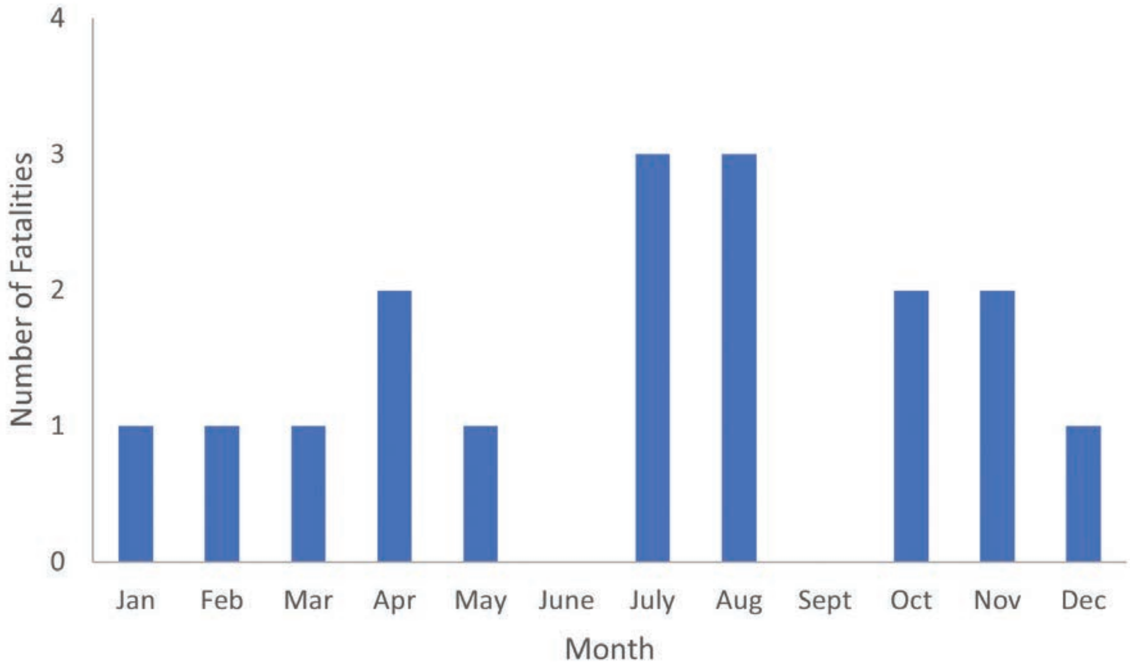


Figure 3-8. Distribution of fatalities by month.

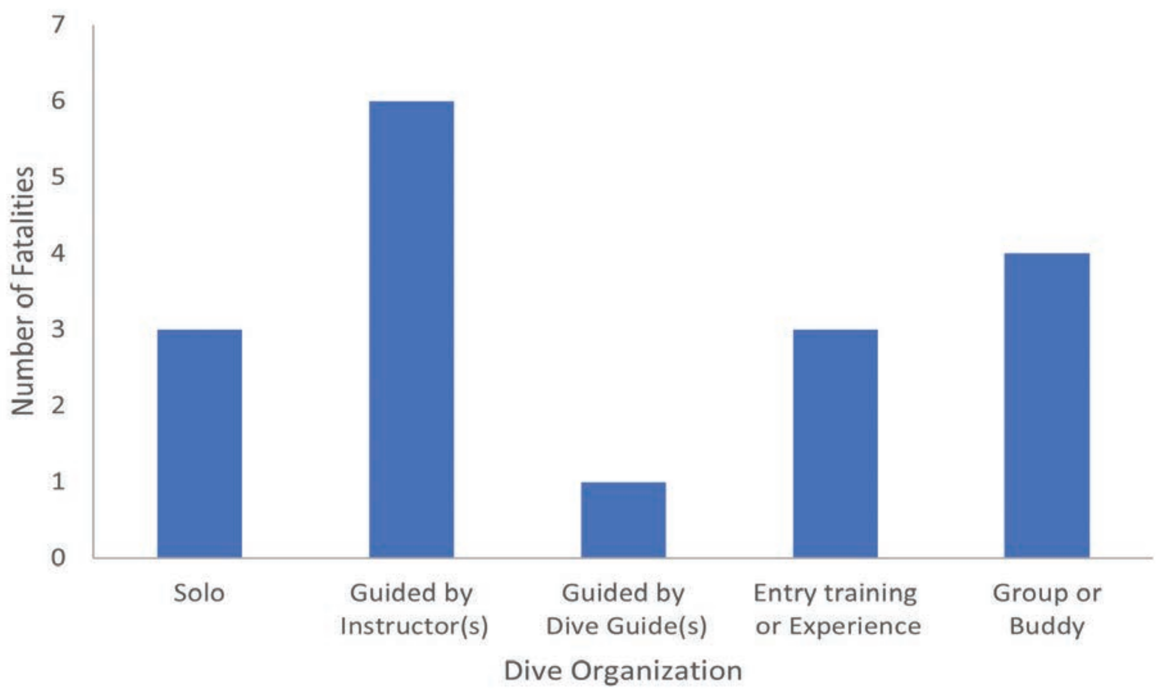


Figure 3-9. Fatalitites by type of dive organization

SECTION 4.
BREATH-HOLD DIVING

Grant Dong, Rhiannon Brenner, Catherine Harris, Elizabeth Helfrich and Frauke Tillmans

INTRODUCTION

Breath-hold diving is defined as holding one's breath while submerged in water. This broad definition encompasses a wide range of activities from children playing in the pool, excursions to a shallow depth in recreational snorkeling, collecting or harvesting game, all the way to competitive freediving. Just as the individuals partaking in these activities, the incidents connected to breath-hold diving are diverse with new trends in water sports emerging often. Thus, monitoring incidents and accidents is of vital importance to inform safety guidelines and raise awareness of the common errors that lead to incidents.

Humans have been participating in breath-hold diving for decades. Freediving populations such as the Ama divers of Japan and Bajau divers of Indonesia have been harvesting crops using freediving techniques for over 1,500 years.[1] Over the years, research has revealed genetic adaptations in the previously mentioned populations as well as in elite free divers including spleen enlargement, increased lung volume capacity, and modulation of numerous biomarkers after just one breath-hold dive. [2, 3, 4]

The body's response to breath-hold and submersion is highly variable across individuals. Experience and training level of an individual will directly influence performance and safety. Most untrained divers will find it difficult to extend their breath-hold beyond one minute. Pain experienced in the ear caused by the differential pressure between the middle ear and external environment will likely influence maximum depths for untrained divers. Learning about these issues as well as practicing breathing and equalization techniques can reduce pain and allow a diver to push past their previous limits. Once a diver is able to reach depths of 30 meters (99 feet), the lungs of an average person are squeezed to their residual volume. At these depths, additional risks are introduced, though most inexperienced divers will experience the urge to breath at these depths, prompting them to rush to the surface before trouble can occur.

It is extremely important to understand the physiological stress placed on the body during breath-hold diving and be trained prior to attempting depths such as these. Some divers ignore this urge to breath when attempting to accomplish a task underwater, such as fishing or harvesting. The pressure to complete the task before returning to the surface may drive the diver to push past his or her limits leading to a blackout due to hypoxia.

Depth limits for trained breath-hold divers involved in freediving are influenced by the level of specialized training and their own personal desires to improve their discipline. There are a variety of disciplines within freediving competitions that are recognized by the International Association for the Development of Apnea (AIDA). Their descriptions and the current depth and time records can be found in Table 4-1.

DAN'S CURRENT RESEARCH AND COLLABORATIONS ON FREEDIVING

Full-face snorkel masks (FFSM) have gained popularity due to their advertised benefits such as allowing for natural breathing and increased visibility. This mask design was modified from a previously existing product line of gas masks. Since being introduced to the market for snorkelers in 2011, multiple incidents leading to devastating accidents and fatalities have been reported; unfortunately, fatality records from FFSM users received by DAN have unclear or unreported causes of death. Divers Alert Network aims to determine if the FFSMs are contributing to the fatalities, and if so, how? DAN is attempting to address this question by working in collaboration with Dr. Rachel Lance at Duke University. Dr. Lance is working to test CO2 build-up and retention in the mask, studying the work of breathing, investigating the handling of the equipment by trained and untrained people, and technical considerations (such as hardware failure).

OVERVIEW OF CASES

Breath-hold incidents have been collected and analyzed by DAN since 2004. Information is obtained through public media, voluntary reports from witnesses or divers placed through the DAN emergency line, and DAN's online Diving Incident Reporting System (DIRS).

Breath-hold diving involves holding one's breath while submerged in water; this definition captures a wide range of activities contributing to the difficulties faced when collecting incident data. The amount of data captured each year is only a fraction of all incidents that occur, however despite difficulties, the amount of data collected continues to increase annually. Similar to other types of diving there is no regulation of common breath-hold activities such as snorkeling, spontaneous breath-hold diving, and recreational spearfishing. A formal reporting system for such incidents and injuries does not exist. Figure 4-1 shows the annual breath hold fatality data collected by DAN's Injury Monitoring initiatives since 2004.

Breath-hold incidents occur across the globe but obtaining information of injuries and fatalities outside of the United States and Canada poses some difficulty. The number of fatalities by citizenship of victims can be found in Figure 4-2 and the location of incidents in Map 4-1 and Table 4-2. However, this data is likely skewed due to lack of formal reporting system, language barriers, etc.

In 2018, DAN captured breath-hold diving information on a total of 61 cases, of which 59 were fatalities and two were determined to not be breath-hold incidents. No injuries were reported this year.

ACTIVITIES WHILE BREATH-HOLD DIVING

Breath-hold diving encapsulates a wide range of activities, the type of activity in which divers were engaged in when the incident or injury occurred are shown in Figure 4-3. Activities were broken down into three categories: freediving, snorkeling, and tasks.

The division between these categories is based on motivation and training. For example, recreational snorkeling does not necessarily require specific training or prior knowledge to participate in the activity, whereas individuals partaking in freediving are more likely to have taken training from available agencies. The 'task' category includes a wide range of activities such as breath-hold spearfishing, harvesting, clearing anchors, retrieving objects, photography, etc. These activities can be broken down futher into more detailed descriptions of the activity such as spearfishing/harvesting, pleasure/sightseeing, training, or unknown/other. The distribution of fatalities by specific activity are shown in Figure 4-4 for free divers and Figure 4-5 for snorkelers.

Of the reported breath-hold fatalities in 2018, Most reported fatalities occurred during snorkeling. This is expected, as the activity is accessible, and participation is unrestrictive. Following the same trend as previous years, freediving has the smallest portion of fatalities recorded. This could be due to the organizational structure and rules that are associated with this activity as well as the selection and specialized training. Due to the complexity of the sport, freediving associations have strict guidelines and safety protocols that must be followed, and any deviation can result in disqualification. With these factors taken into consideration, it explains the relatively low rates of incidents despite pushing the boundaries of physiological limitations.

Combining any activity while participating in diving activities adds additional risks that can lead to injury or death. Activities such as spearfishing, photography, game collection, etc. while freediving can lead divers to descend deeper than originally planned or delay ascent too long as they wait for the perfect shot or opportunistic catch.

The mean age of the victims involved in different breath-hold activities is shown in Figure 4-6, and age distribution of breath-hold fatalities in 4-7. The age of snorkeling victims was on average older than freedivers, which is consistent with previous reports. While most victims were older, the age range of victims in this activity is quite large. This indicates that health-related factors may play a role in snorkeling injuries and fatalities.

The statistics presented in this chapter reflect what is reported or discovered by DAN, but it is important to

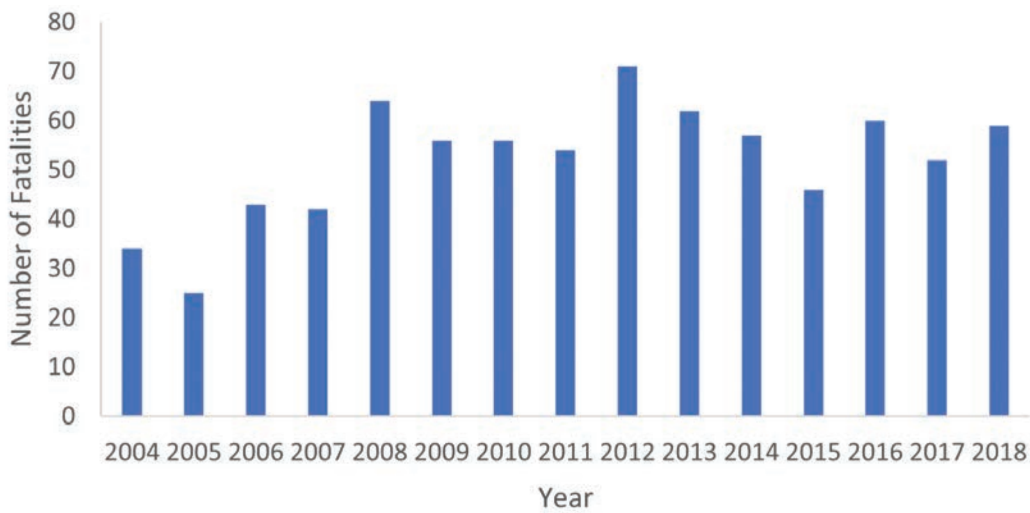


Figure 4-1. Breath-hold fatalities between 2004 and 2018 (n=781)

Discipline	Description	Record Performance			
		Women		Men	
Static apnea (STA)	*Resting, immersed breath-hold in controlled water (usually a swimming pool)*	9:02 minutes	June 21, 2013	11:35 minutes	June 8, 2009
Constant weight (CWT)	*Vertical self-propelled swimming to a maximum depth and back to the surface; no line assistance allowed*	160 meters	August 17, 2002	214 meters	June 9, 2007
Free immersion (FIM)	*Vertical excursion propelled by pulling on a rope during descent and ascent; no fins*	107 meters	July 26, 2018	130 meters	July 18, 2018
No limit (NLT)	*Vertical descent to a maximum depth on a weighted sled; ascent with a lift bag deployed by the diver*	257 meters	October 13, 2019	300 meters	July 2, 2016
Dynamic without fins (DNF)	*Horizontal swim in controlled water*	92 meters	June 11, 2019	300 meters	July 2, 2016
Constant weight without fins (CNF)	*Vertical self-propelled swimming to a maximum depth and back to the surface; no line assistance allowed*	130 meters	October 18, 2015	146 meters	November 1, 2015
Variable weight (VWT)	*Vertical descent to a maximum depth on a weighted sled; ascent by pulling up a line and/or kicking*	208 meters	March 7, 2019	250 meters	October 13, 2019
Dynamic with fins (DYN)	*Horizontal swim in controlled water*	98 meters	October 16, 2019	110 meters	August 5, 2019

Table 4-1. AIDA-recognized competitive freediving disciplines and record performances (current as of March 2021)

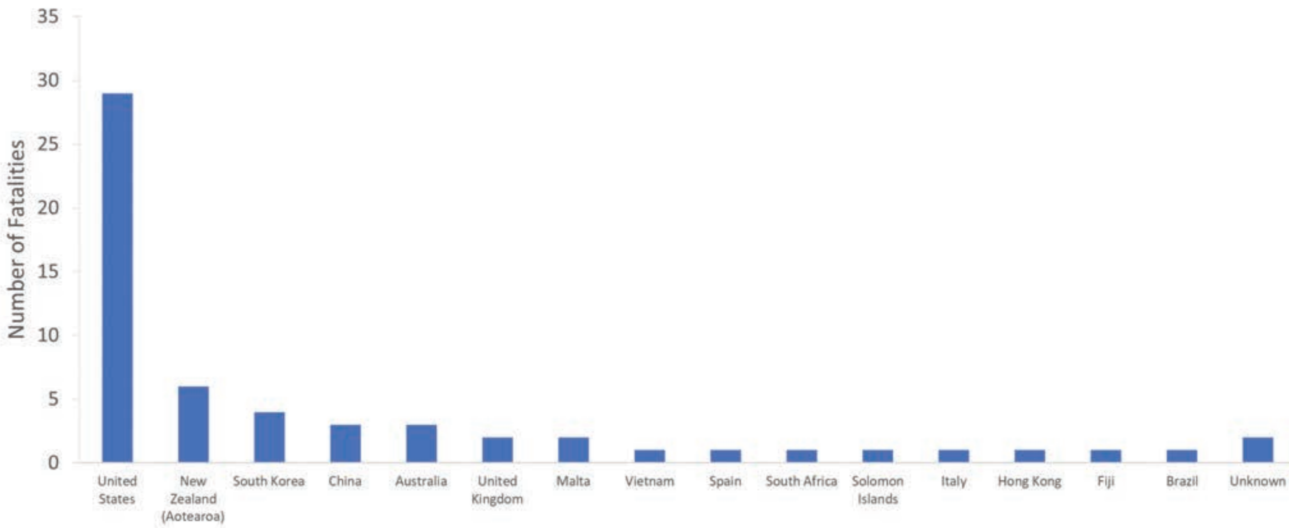
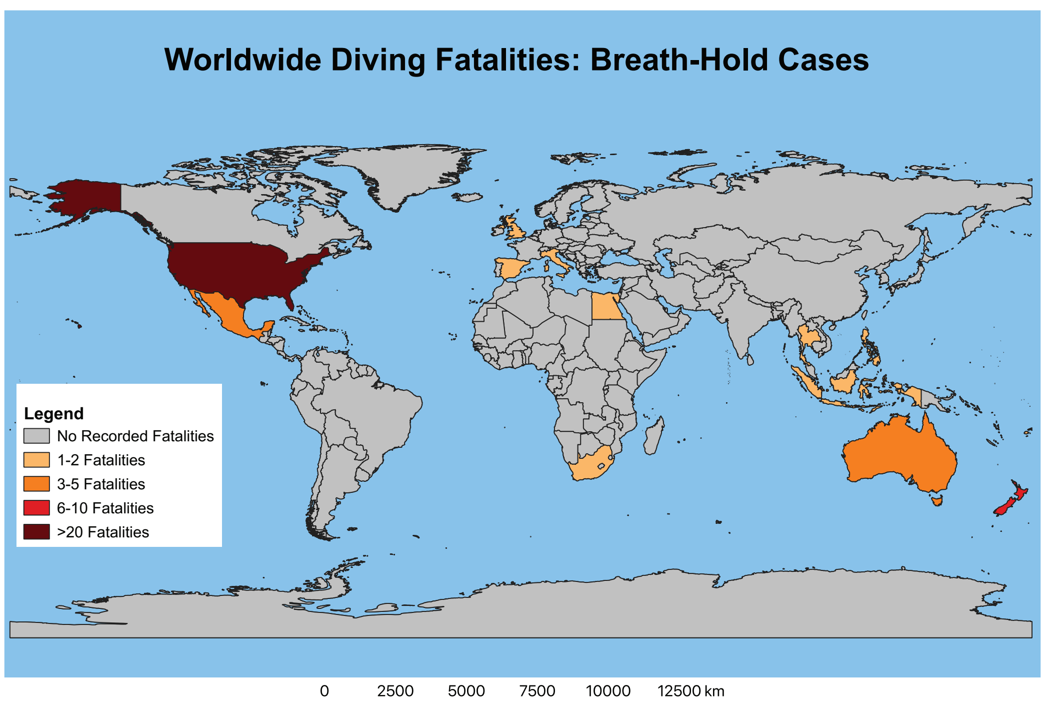


Figure 4-2. Breath-hold fatalities in 2019 by citizenship.



Map 4-1. Breath-hold fatalities by location of incident

note that this is likely an underrepresentation of the total incidents that occur in breath-hold diving. DAN is actively working to improve our methods of collection and understanding of breath-hold incidents.

SELECTED BREATH-HOLD CASES:

Case 2657. A male diver in his sixties went snorkeling in an area with significant rip currents. These areas were evident from the beach and marked by warning signs. After he made his entry, he was caught by the current and was last seen attempting to swim directly against the force taking him out to sea. Shortly after, he was observed offshore and adjacent to the rip current floating motionless. He was retrieved and brought to shore where he was pronounced dead. Medical examination showed a history of hypertensive cardiac disease and toxicology was positive for amphetamines and benzodiazepines.

Commentary: *The drugs may have clouded his judgement both in planning and executing his dive as well as the emergency procedure for dealing with rip currents. In addition, the amphetamines may have contributed to a deadly dysrhythmia that caused loss of consciousness and subsequent drowning.*

Case 2718. A thin woman in her mid-twenties was snorkeling from a charter boat with a group of friends in moderately rough surface chop. She was separated from her tour boat and later discovered missing during a head count of all snorkelers aboard. The Coast Guard was called for the search. She was later found face down in the water without her snorkel or mask. Friends of the victim reported that she had complained earlier in the day of not feeling well, but could not be specific in her ailments. Medical examination revealed ketoacidosis.

Commentary: *Her friends remarked she felt unwell that morning and medical examination revealed ketoacidosis, a medical condition associated with diabetics. She was described as a thin woman. It is possible this diver had a medical history of diabetes that we are not aware of that contributed to this accident. An important rule for all divers of all kinds, but especially breath-hold divers, to dive with a dedicated buddy.*

Country	n
United States	22
Cayman Islands	9
New Zealand (Aotearoa)	6
Australia	5
Mexico	3
Malta	2
Seychelles	1
Saint Kitts and Nevis	1
Philippines	1
Solomon Islands	1
South Africa	1
Spain	1
Italy	1
Indonesia	1
Fiji	1
Egypt	1
Thailand	1
Bahamas	1
Total	**59**

Table 4-2. Breath-hold fatalities by location of incident

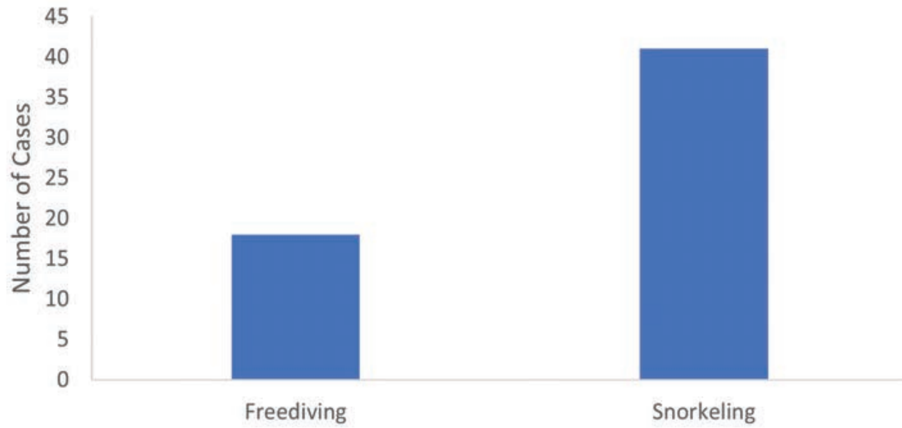


Figure 4-3: Disctribution of breath-hold fatalities by activity category in 2018

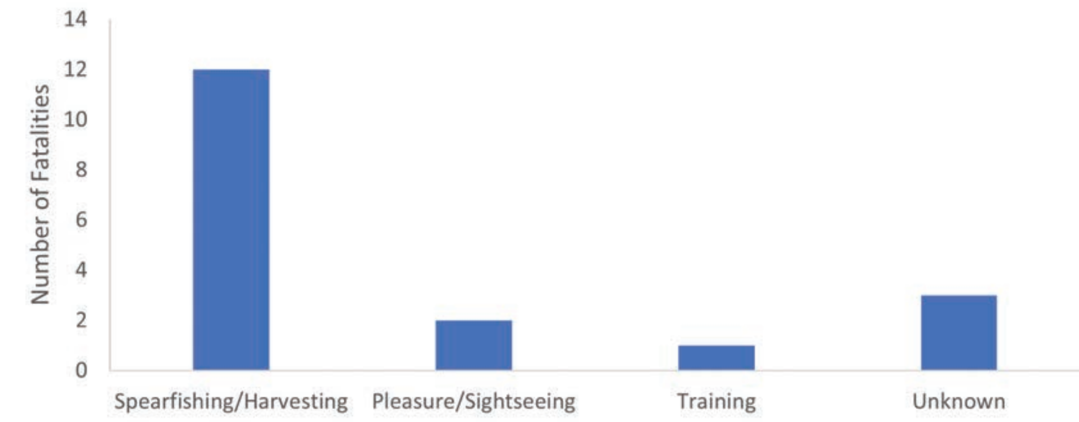


Figure 4-4: Distribution of freediving fatalities by activity category in 2018

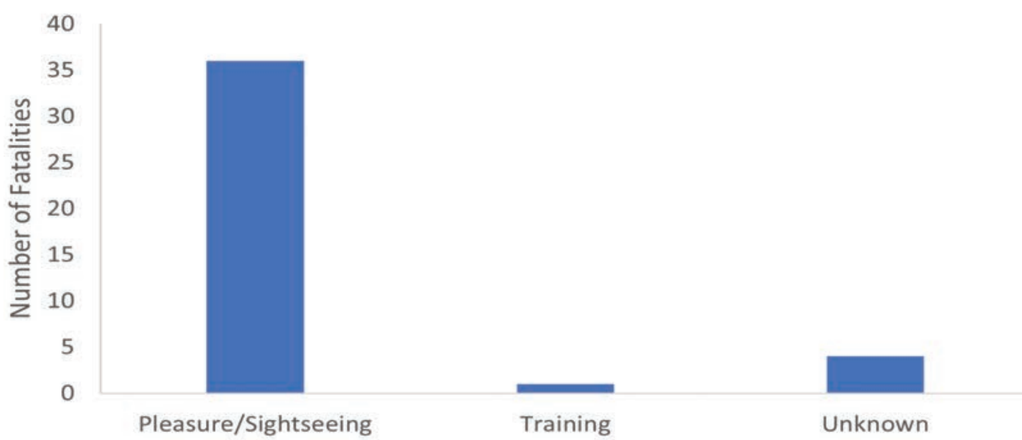


Figure 4-5. Distribution of snorkeling fatalities by activity category in 2018

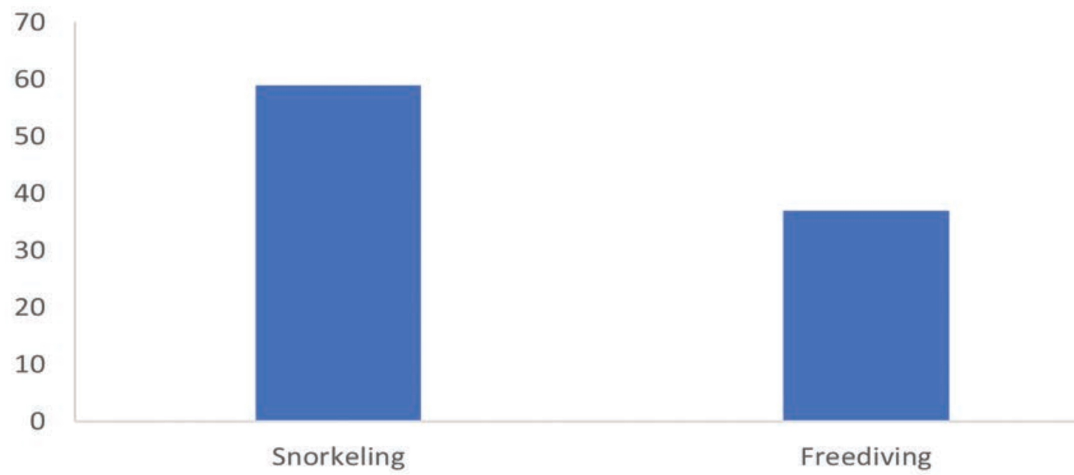


Figure 4-6. Average age of victims by diving mode preceding the incident in 2018

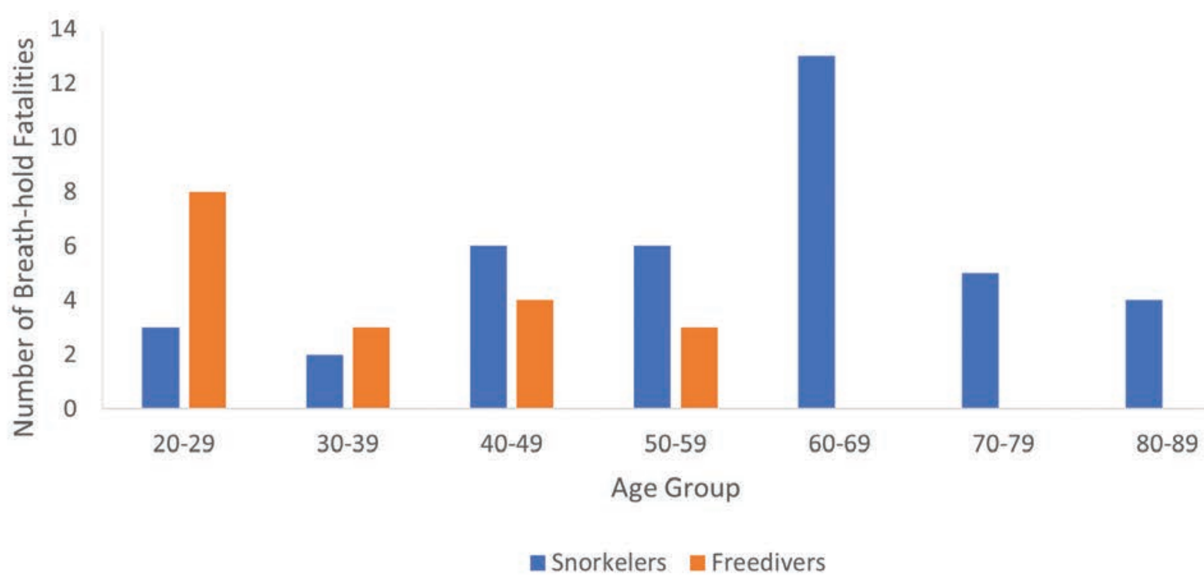


Figure 4-7. Distribution of fatalities by age group in 2018

Case 2715. A male diver in his 40's was snorkeling with his young children in calm water. Shortly after entering the water, he lost consciousness. The diver was in poor physical shape and was obese. Following an autopsy, medical reports found over 75% occlusion of his right and left main coronary artery and hepatosplenomegaly.

Commentary: *A cardiac etiology is suspected.*

Case 2706. One evening a male breath-hold cave diver was going for a personal best depth record with a buddy. The diving conditions were reported to be turbid and stormy. On previous dives the visibility was reported to be poor with very little ambient light at depth. On their last dive, his buddy thought he was ascending with him but could not tell where he stopped due to the poor visibility. The diver was later found inside the cave by rescue divers at over 150 fsw with his 15 pounds of weight still around his waist, leaving him negatively buoyant. The diver had no known medical conditions but had a history of smoking. The diver had reported visual field narrowing and leg numbness during previous breath-hold dives.

Commentary: *High suspicion for hypoxia during ascent. Poor visibility and over weighting in this smoker going for a personal best may have contributed to this incident.*

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SECTION 5.
INJURY MONITORING

DAN RESEARCH IN THE AGE OF 'BIG DATA'

Peter Buzzacott, Anna Maese, Tara Nowrowski, Leah Potts and Frauke Tillmans

INTRODUCTION

The number of college football games that are played each year is on record. However, unlike college football, however, there is no register of recreational scuba divers, nor is there a database of how many dives we make each year. This makes designing safety initiatives especially difficult.

DAN's mission is to promote and support underwater dive research and education, particularly as it relates to the improvement of dive safety, medical treatment, and first aid. DAN strives to provide the most accurate, up-to-date, and unbiased information on issues of common concern to the recreational diving public, primarily for diver safety. Therefore, keeping a finger on the pulse of recreational divers, their diving behavior, and diving injuries is a high priority at DAN.

Fulfilling our mission requires not just the development of general diving injury prevention resources, but also researching groups of divers who may be at elevated risk (compared to other divers). In recent years DAN has promoted safe diving practices to a number of targeted groups, including but not limited to recreational lobster divers, technical divers, nitrox divers, and divers returning after an extended break from diving.

To do this effectively, DAN conducts research among our members at inland dive parks, on dive boats, and at public boat ramps. DAN has also looked to large public health datasets for knowledge of recreational diver characteristics, diving participation, diver behaviors, and diving injuries.

WORKING WITH BIG DATA

In 2015, a systematic search was made within two large public medical research databases, PubMed and ProQuest. PubMed, based at the U.S. National Library of Medicine, contains more than 30 million biomedical literature references. ProQuest, headquartered in Ann Arbor, specializes in cataloguing library content of all types, including theses, newspapers, e-books, journals, periodicals, and digitized historical collections. Figure 5-1 shows the results of the initial search, which found over 100,000 potential leads to explore.

Almost all were false leads or dead ends, but after manually sifting through this enormous collection, 83 databases were identified as potentially relevant to diving (that is, they may include some data about divers, diving, or diving injuries).

Next, a spreadsheet was created listing each potential source of data. Some of these sources were fully searchable online, while others were pay-walled or not publicly accessible (however, the results of a specific search may be ordered). For example, the EpiCenter is

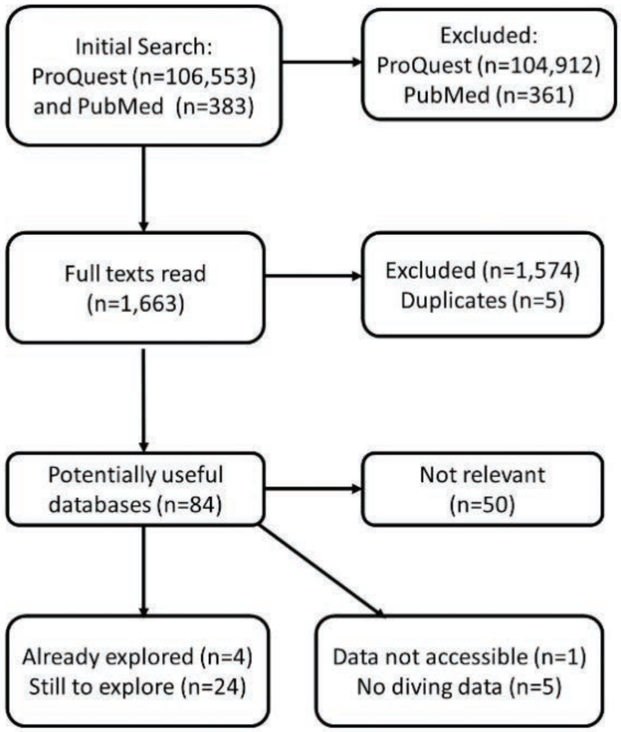

Figure 5-1: Flow of compiling data for injury monitoring

a public health database managed by the Californian Department of Public Health. Anyone interested in health in California can simply visit the EpiCenter, type in whichever search criteria they are interested in, (for example mortality from "falls" in 2018, by county), and the results can be exported to an Excel file.

Effort continues to be made towards harnessing diving data fully within these large databases, meanwhile DAN has already had three notable successes in this regard:

The Canadian Hospitals Injury Reporting and Prevention Program (CHIRPP) collects data about injuries from patients presenting at emergency departments, including 20 Canadian hospitals. Originally started in 1990 with a focus on pediatric hospitals, it soon expanded to include general hospitals, and today has more than 3.2 million records nationally.[1]

DAN contacted the Public Health Agency of Canada, and an agreement was struck to analyze their data for scuba diving injuries. Ethical approvals prevented us from receiving the raw data (hospital records), so our Canadian colleagues had to conduct the data analysis at their end. This is not unusual in collaborative projects consisting of sensitive data.

Scuba diving cases were found either by a code '1167' for scuba or by searching patient records for key words.

Data shows that for every million pediatric patients seen at the Emergency Department (ED) in CHIRPP enrolled hospitals, only about 15 were seen for scuba diving injuries.[2] Among adults, 16.5 diving injuries were found per 100,000 ED presentations, making adult injuries a rare occurrence, but over ten times more common than in children (at 1.5 per 100,000 patients).[2]

These findings support the rationale that any hospital ED can phone DAN Medical Services at any time, on any day, and speak with a trained medic about diving injuries.

When our results were published in the prestigious journal Public Health, it raised awareness of this resource among emergency department clinicians everywhere. The message being; "If you are presented with a diving injury, you can call DAN for expert advice".

The compilation of the National Electronic Injury Surveillance System (NEISS) has been a truly Herculean effort. Currently, trained data recorders (mostly trained nurses) code every injury that arrives in the ED of around 100 US or US territory hospitals. Each ED has a different weighting, depending on where they are and how many cases they treat each year. By combining those weights, it is possible to generate national estimates for the roughly 5,000 EDs in the US and US territories. DAN researchers were the first to interrogate the NEISS for diving injuries,[3] eventually resulting in an analysis of multiple years of data (2006–2015).[2]

The analysis required us to meet three strict conditions when compiling the data:

- Any generated estimate must be >1,200 injuries
- All reported variables must have >20 actual cases treated at an ED
- There must not be a coefficient of variation <30%

Without these conditions the results would not be reliable.

The last of those conditions initially proved rather challenging, but kind assistance from the NEISS project lead at the Consumer Product Safety Commission saw DAN overcome that hurdle. We were able to combine multiple years of data, something that had not been done before for scuba diving.

The combined dataset contained over 140 million injuries seen at US EDs over ten years. Scuba related injuries averaged 1,400 cases a year. Males accounted for 75% of the scuba cases, and were an average of 37 years old, while females averaged 41 years. Around 80% were treated and released or released without treatment. Ear injuries were most commonly seen, followed by injuries to more than 50% of the body (e.g. DCS). For a full description of the results, including what injuries the divers presented with, please see the published paper.[2]

The Behavioral Risk Factor Surveillance System (BRFSS), established in 1984, is based at the Centers for Disease Control and Prevention (CDC) and collects telephone survey data in 50 states, year-round, from around 400,000 people annually. In 2011, more than half-a-million telephone interviews were conducted breaking the record for the largest telephone survey in the world.

That same year, a new technique, called "raking," was used on the data, which gave a weighting to each person's responses in order to make the huge sample more closely resemble the wider US population. The raking method, otherwise known as 'iterative proportional fitting', is still used today. More significantly, 2011 was also the first year the BRFSS included questions about the types of physical activity people engaged in, with participants able to choose from a list which two activities they most actively participated in within the previous month. Scuba diving was on the list of activities, and was also included in 2013, 2015, 2017, and most recently, 2019.

Our initial analysis of three years of combined BRFSS data, conducted in 2017, was published in 20184. We compiled over 61-million person-years of data, and from this, extracted more than 9,000 person years of diver survey information.

These active divers accounted for 0.02% of the total sample. We matched each diver with three other people who were also active, the same age and sex, and lived in the same state and then we compared them. California and Florida made up one third of the scuba divers, they dove once per week, for two hours on average (likely two dives per diving day, on average).

They had a modest body mass index, and overall very few of these active divers had any serious medical history, such as stroke, heart attack, cancer, asthma, diabetes, or kidney disease. For more information about this huge cohort of active scuba divers, please see the original publication. [4]

THE FUTURE OF BIG DATA

DAN researchers are currently working on two enormous datasets and hope to describe them in next year's Annual Diving Report. The largest has the equivalent of over one billion months of data, (that is, data covering about 100 million person-years of health and wellbeing information in US residents). If recreational divers make up even 0.02% of those participants, that proportion will represent a large number of divers.

The data contains health and behavior information that has not been described in recreational divers before. All of the data described above is anonymous and each project is assessed by the DAN Institutional Review Board. For the next two projects, the data is already de-identified and publicly available online. Furthermore, when it comes to surveys, each participant will also have given their consent to participate.

It is even possible some of the random participants in the world's biggest annual health surveys have been DAN members and, though we will never be able to identify any such individuals, we at DAN Research thank you. In the same way that each vote counts in an election, you have anonymously contributed to diving safety. Plus, in next year's DAN Annual Diving Report, you will literally be one in a billion.

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APPENDIX A: DIVING EQUIPMENT FAILURES

A RETROSPECTIVE REVIEW OF SELECTED EQUIPMENT RELATED CASES JUNE 2017 TO JUNE 2020

DAN SAFETY SERVICES

Francois Burman

INTRODUCTION

Diving accidents related to equipment failures can occur both in and out of the water. Accidents that occur in the water present a great risk of injury to the individual diver, especially considering the possibility of drowning or forced rapid ascent. In contrast, accidents that occur out of the water present a greater risk to anyone in close proximity to the equipment. DAN has a repository of incidents and accidents from direct reporting by telephone or email, as well as through the Diving Injury Reporting System (DIRS).

Reports received by DAN can be subjective in nature and lack important details, limiting the amount and accuracy of the data. While some reports are supported by witness testimonials, most incidents are reported by only one individual. Delayed reporting also leads to confusion of events or divergence of information in different witness accounts. The consequences to both, people and equipment involved in an incident, are generally undisputed, allowing for a degree of post-accident analysis.

Over a period of 3 years, information from 21 accidents has been collected and evaluated by DAN. Initial reports were based primarily on accounts by the those directly involved and affected, although in some cases information was limited in unobserved fatalities. DAN has been able to determine the likely root causes and provide recommendations to prevent, or at least mitigate, future accidents. It is important to evaluate these situations both to educate the dive community on best practices as well as monitor related equipment failures that manufacturers may need to consider.

Equipment accidents can generally be divided into three categories:

- Mechanical failures
- Fires, and
- Human-induced actions

One could of course present the argument that in all cases human factors are applicable. As accidents are usually the result of a sequence of events — often referred to in terms of James Reason's Swiss Cheese causation model, the final cause could be related to a combination human error and equipment failure, together with being on the wrong side of Lady Luck. Diving equipment accidents appear to be probabilistic in nature. The primary question of interest here is relatively straight-forward: What was primarily responsible for these equipment failures?

A review of 21 cases, likely representing only a small number of actual occurrences, suggests that equipment manufacturers are seldom at fault, except in instances where the victim exhibited a degree of ignorance.

ASSUMED CAUSES

A realistic list of potential causes could include any one or a combination of the following:

- Equipment design flaws, either mechanical or ergonomic in nature
- Production flaws
- Inadequate training and skills
- Lack of personal care of equipment
- Lack of maintenance of equipment
- Complacency, lack of discipline, and poor understanding of the risks, or
- Issues out of the control of the victim

REPORTED FAILURES AND ACCIDENTS

The 19 reported cases can roughly be divided into the 3 previously mentioned failure categories:

(1) Mechanical equipment failures

- Filling whips 2
- Breathing hoses 3
- First stage regulators 5
- Scuba cylinders 3

(2) Equipment fires

- First stage regulator 1
- Rebreathers 2

(3) Human errors

- Mismatched threads in assembly 1
- Buoyancy compensator 1
- Contaminated breathing gas 1

Through this presentation of 9 cases selected from this list, some perspective to answering the enigma is provided. It should be noted that all cases relied on reports from first or second-hand witness accounts.

The accuracy of data has not been tested and is based on photographs, accident reports, and/or medical notes. However, each case as presented in this report has been reviewed and verified by the person who initially reported it to DAN.

In most cases, there have been a sufficient number of similar cases reported to provide some degree of consistency in the findings.

MECHANICAL FAILURES

CASE 1: Cylinder filling whip (high pressure hose)

Location: Caribbean university scientific diving filling station

Activity: Refilling scuba cylinders

Accident reported firsthand by the victim to the author.

A series of scuba cylinders were in the process of being filled using high-pressure fill whips (hoses) attached to a charging manifold. The charging system was set to around 3,000 psi and all of the whips were stainless-steel braided and PTFE-lined and rated to 4,500 psi (31 MPa). All the whips were subject to regular visual inspection over the working period of 9 years.

On the date of the accident, one whip failed at the crimped fitting attached to the charging manifold valve. The operator suffered superficial abrasions on the chest and face, narrowly missing the left eye, caused solely by high pressure gas ejection. Severe, temporary hearing loss was experienced in the left ear with the potential for a degree of permanent loss.

The probable cause of such accidents could be one of two things, or a combination of these. (1) Fatigue, exacerbated by a lack of support to the static hose end (where it attaches to the manifold valve), and/or (2) a manufacturer production fault (the inadequate or compromised crimping of the fitting to the hose-end).

Risk mitigation activities should focus on three specific aspects:

(1) Procuring appropriate and certified products, that can be traced back to the manufacturer.

(2) Regular and rigorous inspections of all hoses, hose ends, and fittings. Particular attention should be paid to mechanical damage, wear, corrosion, pinching, or significant scuffing of hoses.

(3) Additionally, periodic hydraulic pressure testing would aid in ensuring the integrity of the hoses.

Whip restraints should be fitted to any hose-end where failure could lead to uncontrolled movements that have the potential to cause catastrophic damage.

In general, it is recommended that filling operators are made fully aware of the risks associated with high pressure equipment. Flexible hoses should be regarded as replaceable items, and a service life of 10 years would usually be considered appropriate. Examples of such failures and one of a typical whip restraint are shown in Figures A-1.

Pictures A-1: A) Filling whip burst at the manifold valve. Credit S. Prosterman; B) Clear indication of failure at the crimped fitting. Credit S. Prosterman. C) Typical whip restraint. Credit Chicago Coupling.

CASE 2: Second stage regulator failure

Location: Florida

Activity: Cave diving (in-water)

Accident reported firsthand by the victim to the author.

The accident occurred during a pre-dive safety drill at 25 fsw (7.7 msw), diving with a side-mount configuration and 2 independent cylinders. Prior to entering a cave, the diver noticed that his BC inflated more slowly than usual before getting a mouthful of debris from his second stage regulator. He switched to his other cylinder but found the second stage regulator difficult to breathe from as well. After aborting the dive and getting back on dry land, he inspected the second stage regulators and noticed a significant amount of plastic 'crystals' at the inlet to one of the regulators.

He cleaned the regulator and swapped out the hoses. Another safety check was done, and he and his buddy then proceeded into the cave for about 30 minutes. Once again, he had trouble breathing and returned, safely, but breathing alternately from one regulator to another. On his return to the surface, he found more of the same 'crystals' in both regulators.

A series of articles in Alert Diver[1,2] discussed the premature degradation of low-pressure braided hoses, manufactured by one specific supplier, using an unsuitable inner lining material. The BC inflator hose, once cut open, showed clear evidence of degradation. However, the two breathing hoses, when sent to the manufacturer, proved to be clean and intact.

This mystery was only solved when the DAN team discovered that the low-pressure hub on the first stage regulator was common to and therefore connecting all low-pressure hoses, which are typically used for breathing, and BC and dry-suit inflation.

The situation was replicated in the DAN office using the failed inflator hose, gravity, and a minor amount of agitation. Crystals passed easily through the low-pressure hub into both low-pressure breathing hoses (Figure A-2).

Similarly, venting one breathing regulator caused air in the system to travel in one direction and carried these particles from the other hoses towards the first stage regulator.

A series of recommendations can be offered to mitigate the risks and any resultant blockages or hose failures.

(1) Remove braided hoses manufactured prior to 2009 and not bearing any clear manufacturer's name embossed or laser engraved on the end fittings.

(2) Perform regular pre-dive inspections of the braided hoses for obvious signs of failure — a soft, 'squishy' feel and easy to kink prior to being inflated.

(3) Ensuring all breathing system components, including all hoses and regulators, are inspected and serviced as per manufacturer's schedule.

(4) Procure products bearing full details of the manufacturer, serial number and working pressure.

Divers should be aware of this infrequent but prevalent risk of premature braided hose failure. High quality and fully traceable products are not prone to this form of failure.

CASE 3: Aluminum oxide particulates in breathing gas
Location: Liveaboard off the Galapagos Islands

Activity: Scuba diving

Accident reported to the DAN medical hotline (MSCC # 177105)

The diver noticed a white powder inside her primary second stage regulator after a dive. When the complete regulator assembly was removed in order to get ready for a second dive, a similar white product (powder or particulates — not specified) was observed on the first stage regulator inlet. This was cleaned with a toothbrush and diving continued. This happened again a couple of days later.

The diver developed minor respiratory symptoms while on board the dive vessel and upon returning home, presented with loss of voice and "burning airways". She also developed ear and eye infections. After consultation with her primary care physician, she was treated with antibiotics for suspected pneumonia. 7 days later she complained that her lungs continued to "burn."

The corrosion reaction between water and aluminum in scuba cylinders results in the formation of aluminum oxide in a white powder form. While it is unusual to visually observe this powder other than during an internal visual cylinder inspection, this oxide product can migrate through the cylinder valve and into the regulator. The powder needs to be in suspension to enter the valve dip-tube. First stage regulators are fitted with sintered metal filters and entrap larger-sized particulates.

In general, aluminum oxide does not appear to be toxic in small doses, although there are anecdotal reports of the product potentially being toxic, carcinogenic, and causing neurological deficits. However, it has been more widely reported that any particulates, aluminum oxide or otherwise, larger than 5µm tend to cause upper respiratory tract issues, whereas those smaller than 5µm are deposited in the lung tissues. The resulting inflammatory reaction of particles smaller than 5µm affects the alveoli in the lungs, presenting as a 'chemical' pneumonia. People with a history of respiratory conditions such as asthma, which this diver had, appear to be more vulnerable to this. This could be the reason for the

Figures A-2: braided hose failure: A) Inflator hose clearly kinked. Credit DAN, B) Branded breathing hose intact; unbranded inflator hose clearly degraded. Credit DAN; C) Regulator low pressure chamber filled with debris. Credit DAN; D) Second stage inlet clogged with hose debris. Credit DAN.

delayed recovery and apparent inefficacy of the antibiotic treatment. Eventually, the lungs do typically expel the contaminant. An example of a clogged regulator inlet is shown in Figure A-3.

The two primary recommendations arising from this case are:

(1) Any form of powder on the internal surfaces of the second stage regulator indicate a failure upstream and should be investigated. The regulator should not be used until the cause has been determined and the regulator is cleaned.

(2) Regular servicing of regulators is extremely important. There are many cases reported where regulator filters have been clogged with significant amounts of white powder (Figure A-3), indicating a lack of servicing.

Figure A-3: Regulator inlet filter clogged with aluminum oxide. Credit: J. Polanco

CASE 4: Rupture of aluminum scuba cylinder
Location: Haifa, Israel

Activity: Filling of scuba cylinders

Accident reported to the author by a scuba-inspection and safety specialist, who received the report from an Israeli agency.

An aluminum cylinder was being filled when it suddenly ruptured, seriously injuring the operator. The investigation revealed that this was a cylinder manufactured from the aluminum alloy 6351-T6 (Figure A-4C), known to be susceptible to sustained load (stress-induced) cracking originating at or near the neck threads. This material flaw was detected as far back as 1981 by a scientist working for an aluminum cylinder manufacturer and was made public two years later. At that stage, disposal of these cylinders was not required, although subsequently some countries have prohibited the continued use of 6351-T6 high pressure cylinders after several reported cracks and cylinder ruptures.

In 1971, and for the first 11 years of aluminum production in the US, the DOT issued unique numbers referred to as Special Permits (SP) and later Exemptions (E) to each manufacturer. Figure A-4B illustrates a common example of a Luxfer cylinder bearing the Exemption number E6498. In 1982, these cylinders were required to be stamped by the manufacturer with the code 3AL (Figure A-4A). Cylinders bearing both 3AL and the SP or E number indicate that these were requalified after 1982. However, this requirement is certainly not well respected.

Regular overfilling as well as cylinders being left at pressure for long periods of time are known to be contributing factors to these failures. However, crack growth is typically slow (measured in years), which implies that annual, careful inspection should determine the presence of a crack long before failure occurs. Eddy current testing, a type of electromagnetic testing that is non-destructive, has proven to be effective in early detection of crack formation and is often used during annual scuba cylinder inspections. All inspection and testing must be done by a formally trained inspector — such as prescribed in the US by the US DOT, CGA or OSHA.

Cylinder producers switched to the aluminum alloy designated type 6061-T6 between 1988 and 1989. There have been no reported cases of sustained load cracking being detected where this alloy is used. Many filling stations have opted not to accept 6351-T6 cylinders for refilling; in some countries these are no longer permitted to be used.

The following recommendations could assist in preventing recurrences of such cylinder failures, especially during refilling:

(1) For the filling station, great care should be taken when accepting alloy 6361-T6 cylinders for filling. At the very least, these cylinders especially need to be checked for compliance with an annual inspection date, including examination by eddy current testing. Inspection should be conducted by a qualified inspection company or inspector known to them.

(2) Any cylinder that is suspected or observed to not meet these requirements should be identified and temporarily removed from service until the matter has been resolved.

(3) Awareness of the related safety concerns is essential for all divers who still own and use 6351-T6 alloy cylinders. [3]

Figures A-4: A) DOT marking on aluminum alloy 6061-T6 cylinder, Credit Luxfer; B) DOT marking on aluminum alloy 6351-T6 cylinder, correctly recertified. Credit M. Gresham; C) Sustained load crack on cylinder internal thread. Credit F. Burman

OXYGEN FIRES

CASE 5:

Oxygen multifunction regulator

Location: Udine, Italy

Activity: Use of an emergency oxygen kit for demonstration purposes during training.

Accident reported second-hand by a DAN colleague in Italy who interviewed the victims.

During assembly of an oxygen kit (Figure A-5B/5C) and subsequent opening of the cylinder valve, a noise emanated from the regulator, immediately followed by a jet of flame for four to five seconds, with two instructors sustaining burn injuries. The regulator's pressure gauge was blown out during the fire, leaving an open port in its place.

It is unclear whether the fire originated at the DISS outlet or the pressure gauge connection installed in the aluminum-bodied oxygen regulator. The term DISS is an abbreviation for the CGA-denoted Diameter-Index Safety System. In these applications, DISS connectors usually incorporate a non-return valve to provide the option of using a demand valve or a free-flow system without needing to use end-caps.

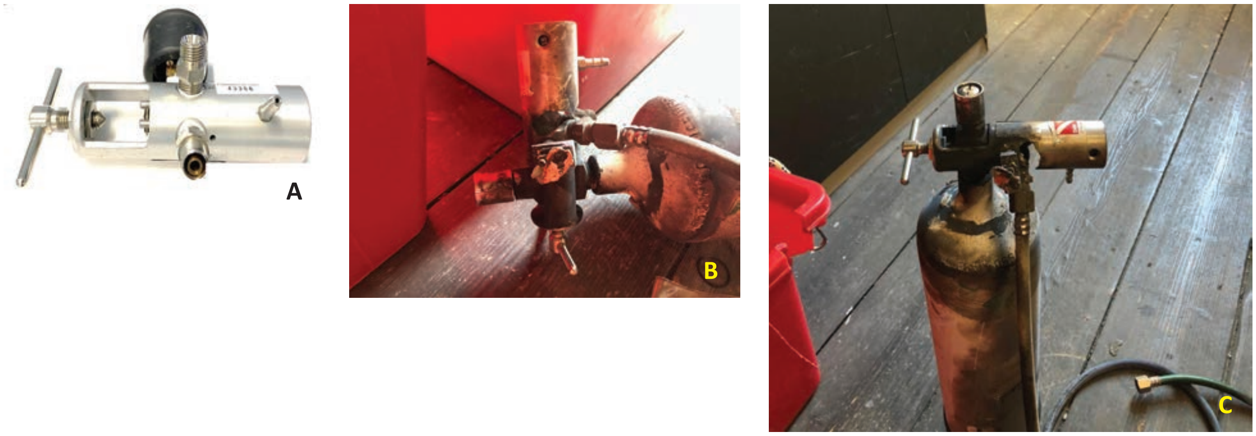
Both the multifunction regulator and demand valve had been in use for over 20 years and had never been serviced. The high-pressure regulator and demand valve were destroyed.

Fire requires three elements to be present: oxygen, fuel, and an ignition source. While there was clearly an excess of available oxygen, the fuel and ignition source can only be speculated on. Typically, in these cases, the fuel would be dust, an oxygen-incompatible lubricant (grease), and/or fingerprint residues (fats, oils, amino acids, sebum, or any other combustible material on the operator's fingers).

The source of ignition is the most difficult factor to isolate. However, based off of research, observations, and accident reports, the source could be any, or a combination of the following: particle impact (when fast moving particles strike a surface in the gas stream), adiabatic compression (very high temperatures that are generated when fast flowing gas is abruptly stopped), friction (rubbing together of valve surfaces when these are opened and close), resonance heating (vibrations cause by gas flowing through small openings), or flow friction (rubbing of fast moving gas against internal pipe or hose walls). These are all typically associated with fires in pressurized lines and components and can be prevented in well-designed oxygen equipment and components, as well as by using safe practices, such as opening and closing valves slowly. There are many other lesser observed mechanisms of ignition, but the five mentioned above are the most likely to occur under these circumstances.

Based on the reported activity at the time of the incident, as well as the location of the fire damage, one might suspect the cause of ignition to be adiabatic compression caused by rapid opening of the cylinder valve, or particle impact from any solid contaminants in the cylinder, the cylinder valve, or the regulator inlet filter (which is most likely).

Aluminum-bodied regulators (Figure A-5A) of this configuration have been involved in many such fires, as noted by the author during a visit to an accident investigation laboratory facility. In fact, the reality is that



Figures A-5: A) Aluminum version of Allied multifunction regulator. Credit F. Burman B-C) Aluminum multifunction regulator fire damage. Credit DAN Europe.

ignition in oxygen systems, even where all the essential elements are present (sufficient fuel and a source of heat), achieving combustion is probabilistic in nature — it is hard to replicate. Despite the wide-spread inappropriate use of equipment materials or designs (such as rapid opening valves) over many years, the number of reported fires is low.

Recommendations to avoid such accidents include the following:

(1) Oxygen cylinder valves must always be opened slowly. 'Slowly' is defined as being around one minute from start to fully open, while paying careful attention to the initial flow. This method is usually companied with a hissing sound. When cylinder valves are tightly closed it is even more critical to control opening so that there are no sudden releases of oxygen towards the regulator.

(2) Oxygen systems require specific cleanliness measures. Any wetted surfaces (meaning surfaces that will be in direct contact with any flowing oxygen gas) should be free from any potential fuel source.

(3) Careful inspection during and after setting up to detect any obvious errors — such as leaks, mismatched threads, or non-aligned parts.

(4) Aluminum bodied resuscitator regulators (Figure A-5A) should be withdrawn from oxygen service. Brass bodied oxygen regulators are safer and have replaced those manufactured from aluminum alloys.

(5) Always follow the manufacturer's maintenance instructions.

CASE 6:
Rebreather — Heliox diluent with oxygen make-up gas
Location: Tulum, Mexico
Activity: Cave diving on a rebreather, preparation on land.

First-hand report given by the victim to the author.

During the pre-dive set-up, the diver 'slowly' opened the oxygen cylinder valve when instructed to by the control system. Ignition occurred immediately with a cracking sound. The high and low-pressure hoses immediately burst into flames with fire exiting though the hose fittings still attached to the regulator.

The subsequent fire caused ignition of the rest of the rebreather (Figure A-6E). As the diver's hand was still on the valve, the fire spread to his hand, forearm and face — he had been leaning over the rebreather to open the oxygen cylinder valve. He immediately jumped away from the burning equipment and the fire on his body was extinguished using water. The resultant injuries included severe burns to his hands, forearms and face (Figures A-6A/6B/6C).

The diver was a very experienced rebreather diver and the equipment was reportedly regularly serviced — it was, in fact, only in its second year of use.

His initial concern centered on the oxygen cylinder, as this was supplied from a local gas vendor. A question was raised concerning impurities in the gas. As with most oxygen fires, the actual cause is very hard to determine precisely, however, impurities (dust, hydrocarbons and other forms of debris) could be the initial fuel and an ignition source.

In the case of most rebreather and oxygen-system diving-related fires, the primary activity at the time of ignition is the opening of the valve. The fire is usually observed at the regulator.

Typical sources of ignition in oxygen systems were listed in the previous case, and the associated reference refers here too. However, this time the sources could be reduced to particle impact (debris) or adiabatic compression (opening of the valve). There was no obvious friction other than in the cylinder valve; being an oxygen-design component, this is not a likely place for friction to be a cause. The flow time appeared to be much too short for resonance or flow friction.

This implies that the likely causes were debris (Figure A-6F, particle impact) or adiabatic heating. Pictures (Figure A-6D) of the regulator indicate that the hoses burst due to rapid over-pressurization, caused by the fire. Debris in the high-pressure regulator inlet fitting before the filter could point to the fuel and/or the cause of particle impact. The burned-out inlet filter, where most of the debris coming into the system would collect, was the likely place for ignition. Rental cylinders are certainly a potential cause of concern in terms of contamination by debris/particulates.

In this case, the valve was opened slowly in accordance with standard, good practice. This would possibly have reduced the speed of the impacting particles, implying that ignition could well have been caused by adiabatic heating — perhaps a function of the valve design.

In light of this, the manufacturer has decided to add system refinements to further slow the initial gas-flow. As a generalization, a diver's perception of slow opening is usually not slow enough.

While the risk of this type of accident could be reduced through refinement of the cylinder valve, the following recommendations remain applicable and should be reinforced through education.

(1) Always maintain cleanliness of all oxygen components and surfaces. This includes using clean and dedicated tools for working with oxygen systems.

(2) Be aware of the potential for solid contaminants in rental gear. Oxygen cylinders must be cleaned thoroughly.

(3) Only use oxygen-compatible lubricants, sealants, seals, and components.

(4) Slow means slow. It should take one minute or more to open an oxygen cylinder or other high-pressure valve. If a valve is stiff, the opening process should be stopped and addressed before continuing, as a stiff valve is hard to control when opening.

HUMAN ERRORS

CASE 7: Cylinder valve rupture

Location: Belgium

Activity: disconnecting cylinder filling whip after charging.

Accident reported by a witness to the author, however the incident report details remain vague due to the shocking nature of the outcome.

A filling whip was being disconnected from an aluminum scuba cylinder when the valve thread failed and ejected the valve upwards. The operator was standing vertically above the cylinder at the time and suffered an instantaneous fatal injury.

The failure was the result of an imperial cylinder valve being mated with a metric cylinder. As far as the witness account goes, the cylinder was machined with a standard European M25 x 2 parallel thread, with 12.7 threads per inch (TPI) and a 60° thread form. The cylinder valve thread was machined with a ¾" x 14 BSP (British Standard Pipe) parallel thread, with 14 TPI and a 55° thread form.

It is hard to imagine the amount of force required to make these two threads match, especially since the cylinder valve was apparently fully inserted so that the O-ring seal was appropriately located on the two surfaces. The aluminum cylinder neck thread, being the softer of the two metals, would likely have been significantly damaged in the process.

This joint was not leaking at the time of the accident. The human errors committed here were, in essence, a combination of total ignorance by the owner of the cylinder, and failure of the operator to adequately inspect the valve and cylinder. The European marking system is rigorous in this regard.

This is not the first of these occurrences, with many more industrial accidents than scuba accidents having been reported. However, despite a large degree of harmonization outside of the USA, different cylinder and cylinder valve configurations remain in place. The recommendations to avoid endangering the lives of anyone in proximity of a scuba cylinder include:

(1) In the United States, the current configuration is ¾ - 14 NPS (National Pipe Straight), parallel, 14 TPI and a 60° thread form. (Figure A-7A)

(2) The international harmonized standard, or ISO standard, for the equivalent configuration is M25 x 2, parallel, 12.7 TPI and a 60° thread form. These are not compatible with each other. (Figure A-7B)

Pictures A-6: Victim and equipment after an oxygen fire (Case 6);
A-C) Severe burns to hand, forearm and face. Credit F. Rueda;
D) Burned inlet filter element next to new filter element. Credit AP Diving;
E-F) Total destruction of rebreather by fire. Credit F. Rueda

(3) In addition, Europe also uses a 25E thread, which is a tapered thread for steel cylinders. The valve thread is nominally 1" (25 mm) in diameter, with 14 TPI, a 55° thread form, and a 12% tape slope. None of these configurations are interchangeable.

The recommendations to avoid endagering the lives of anyone in proximity of a scuba cylinder include:

(1) Being aware of the different configurations.

(2) Inspecting both components for clear indications of markings, which is not always easy to determine without proper training. This is not likely to occur within the USA as cylinders are usually sold with valves already fitted, but could occur in regions where valves and cylinders could be purchased independently of each other and supplied from different regions of the world.

(3) Filling cylinders in a cage or cabinet, which, of course, is not a guaranteed method of protection once cylinders have been filled.

Figures A-7: Different cylinder valve configurations: A) ¾- 14 NPS (National Pipe Straight), United States standard, DGX DX-722401-O2; B) M25 x 2- ISO, international harmonized standard, IMCA SF 01/16.

CASE 8: Buoyancy compensator (BC)

Location: Seattle
Activity: scuba diving (in-water)
Reported second hand to the author.

A diver attempted to repair a 1" (25 mm) tear in his BC through to the bladder, using only an adhesive rather than the recommended combination of patch and adhesive used for this application. The diver waited a suitable amount of time for the adhesive to dry before use. While inflating his BC at around 45 fsw (15 msw) the tear re-opened. He was over-weighted on this dive but managed to ditch his weights. The ascent was difficult to control but the diver was asymptomatic upon reaching the surface. In terms of recommendations, one can only point to ignorance and attempting to under-estimate the importance of maintaining and handing essential life-support equipment. Divers should always be prepared to ditch their weights in the event of an emergency with a BC.

CASE 9: Contaminated breathing gas

Location: South Dakota
Activity: scuba diving (in-water)
Accident reported to the DAN medical hotline; victim called the author 6 weeks later.

The diver was observed having a seizure at 26 fsw (8 msw) with a dive time of approximately six minutes and made a rapid ascent. He was found unconscious at the surface. Although he required resuscitation at the scene, he made a full recovery.

He recalled that the air tasted strange before the dive and recovered both his cylinders in the same condition as they were on the day of the accident. Air quality samples were drawn and sent to a testing laboratory. Both came back as having failed to meet the specified breathing air requirements. Tables A-1 and A-2 present the detailed gas analyses. In the USA, the required limits for scuba breathing air are specified as CGA Grade E5 . The actual values for carbon dioxide in both cylinders were well above the stated limits but would likely not have any profound effect after 6 minutes at 26 fsw (8 msw).

The actual values for carbon monoxide were extreme. Compensating for depth, these values would have the same effect on the human body at the surface as 530 ppm and 572 ppm respectively.

Table A-2 illustrates the potential effects of elevated carbon monoxide at the surface. In concentrations in both above cases, loss of consciousness would occur very quickly. The methane levels were also unacceptably high and present further complications of asphyxia. The air was clearly and catastrophically toxic.

An overheated compressor, where the lubricating oil reaches a high-enough temperature to combust, could cause elevated carbon monoxide levels. This is usually accompanied by an associated odor. However, methane and carbon dioxide are usually not associated with incomplete combustion of breathing air compressor oils.

It is more likely that contamination occurred externally to the compressor and was drawn in through the intake. This is substantiated by the strong odor, the presence of unknown (not analyzed) elements, methane, carbon dioxide, and no indication of the compressor overheating

An analysis of the compressor oil that was used at the time of filling these cylinders would have easily confirmed whether this was the cause.

The primary recommendation here—and lesson to all scuba divers, professionals, and filling station operators—is that the specified limit for odor as 'none' is a critical parameter to assess. Good air should not have any odor, let alone a strong odor without a clear indication of the source.

Elements	Analysis cylinder ‘yellow’	Analysis cylinder ‘blue’	Limits (CGA - E)
Oxygen (%)	20.3	20.2	20–22
Carbon dioxide (ppm)	3263	3135	1000
Carbon monoxide (ppm)	490	503	10
Methane (ppm)	378	392	25
Moisture (ppm [°F])	22.3 [-65.9]	22.4 [-65.9]	67 [-50]†
Oil & particles (mg/m3)	<1	<1	5
Unknowns	Detected	Detected	N/A
Odor	Strong	Strong	None
†Not stated but generally accepted for pressures up to 2900 psi			

Table A-1: Gas analysis of two cylinders (Case 8) six weeks after the incident

CO [ppm]	%COHb [7]	Effects on the body
≤5	≤1	Normal
10	1.8	Normal
25	3.5	Maximum allowed in the workplace
30–60	5–10	Maximum safe level
60–150	10–20	Headache, breathless
150–300	20–30	Add dizziness, nausea, impaired dexterity
300–650	30–50	Add vomiting, confusion and loss of consciousness
700–1000	50–65	Organ impairment, coma, fatal if not treated
>1000	>65	Fatal
Note: In smokers, %COHb may vary between 1.5 percent and 14 percent		

Table A-2. Potential effects of elevated carbon monoxide (CO) at the surface

In addition to this, all compressor facility operators and/owners should do a careful risk assessment of the area surrounding the placement of the compressor intake. This is not only important prior to the initial installation, but also at regular intervals thereafter, as building or external situations can change. In addition, this should be done each time a compressor is run, specifically assessing whether there are any chemicals being stored close by, cleaning processes underway, or external events such as motor vehicles, restaurant fumes or other conditions as described in the article referenced above. Regular compressor maintenance and air quality testing would reduce these risks even further.

FINAL WORDS

While this only represents a small sample of failures occurring over a limited period, in all cases, information has been gained either first or second hand rather than from media reports.

The root cause of all of these accidents, as suggested in the introduction and evident in this review, is the interaction between people and their equipment. Bad luck is, in reality, an illustration of the probabilistic nature of all failures: a chain of events (perhaps only contributory) leading to failure and the validation of the Swiss Cheese Model concept. Basic good practices would serve to break the chain at several different stages, significantly reducing the chance of failure and associated injury or fatality.

Failures in all of these cases thus relate, primarily, to human behavior. This is something that can be addressed through heightened awareness, consistency in following training, constantly updating skills, and ensuring that equipment is inspected and maintained appropriately and on time.

Accidents can be avoided or at least reduced by addressing human factors as highlighted in this report.

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7. COHb values are interpolated linearly between known values, but the correlation is only linear for the first few hours of exposure. Typical dive times allow for this. The values are rounded off to the nearest integer for values over 3.5 at the surface.

APPENDIX B
TRAINING AND EDUCATION

DAN SAFETY SERVICES

Jim Gunderson

INTRODUCTION

DAN's mission is to make diving safer through awareness, education, prevention, and preparation. A fundamental part of this mission is to have the appropriate first aid equipment available at every dive site, and people trained to use it.

In 1991, DAN recognized the need to have people trained to deliver oxygen in the event of a diving emergency, and thus, the DAN Oxygen First Aid Training Program was born. By August of 1991, DAN had trained over 1,000 providers. Over the years, the DAN First Aid courses have evolved, expanding what is covered in a course, and adding additional courses for divers and non-divers to learn and develop the necessary skills to render aid in the event of an accident or injury, be it from diving, or an every-day occurrence.

DAN first aid courses were developed by experts in diving medicine and scuba diving educators to provide individuals with the skills and confidence needed to respond appropriately in an emergency. These easily understood courses prepare divers to manage scuba diving accidents and treat diving injuries, but they also provide training that is applicable outside of diving. All courses meet International Liaison Committee on Resuscitation (ILCOR) and American Heart Association (AHA) guidelines.

In 2018, DAN offered seven different courses to address delivery of oxygen for diving emergencies, CPR, first aid, and other necessary skills to assist injured divers specifically but the general public as well.

INDIVIDUAL COURSES

Of the seven courses DAN currently offers, Emergency Oxygen for Scuba Diving Injuries, (EO2), remains the most popular (see Figure B-1).

EO2 is geared for training people to administer emergency oxygen in the event of a scuba diving incident or accident. The skills are also applicable for any emergency related to a submersion event, such as freediving or swimming.

DAN also offers two different CPR/First Aid courses: **Basic Life Support CPR with First Aid (BLS)**, and **CPR: Health Care Provider and First Aid (HCP)**. The BLS course features 1-rescuer, adult-only CPR, with a more involved first aid component. HCP offers 1- and 2-rescuer, adult, child, and infant CPR, in addition to essential first aid skills. The BLS course is also approved by the U.S. Coast Guard as meeting the first aid and CPR training requirements for seafaring individuals.

The Neurological Assessment (Neuro) course teaches how to properly manage injuries with neurological implications. Participants of this class will learn to recognize these injuries and properly perform a neurological assessment, as well as what information to collect and relay to emergency medical services. Recognizing symptoms of neurological distress and responding quickly can shorten recovery times and improve long-term outcomes.

DAN's **First Aid for Hazardous Marine Life Injuries (HMLI)** course addresses injuries that may occur from venturing into the ocean or even simply consuming food from it. It teaches students the how to identify specific types of marine life injuries and the first aid skills required to treat them.

COMBINATION COURSES

DIVING EMERGENCY MANAGEMENT PROVIDER (DEMP)

DEMP takes the diving-centric portions of BLS, EO2, Neuro, and HMLI, and rolls them all into one course. This course is ideal for any diver, but especially rescue divers. This course focuses specifically on diving injuries, and provides divers and their surface support teams with first aid training for interim care until emergency medical services are available.

DIVING FIRST AID FOR PROFESSIONAL DIVERS (DFA PRO)

DFA PRO was originally designed for diving professionals and volunteers at the request of the Association of Dive Program Administrators (ADPA) to address their need for a comprehensive course. DFA Pro includes all elements of DAN core first aid courses, plus additional information and resources applicable to dive professionals in a variety of settings. This course is also approved by the U.S. Coast Guard as meeting the CPR and first aid requirements for captain and mate licenses and it is also accepted by the American Camp Association for staff CPR and first aid requirements.

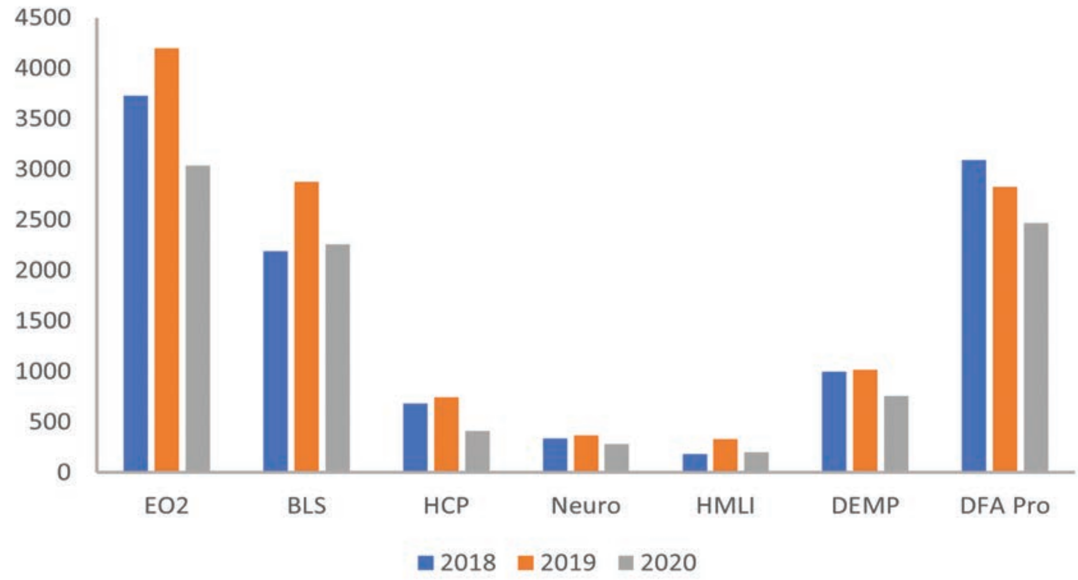

Figure B-1: DAN Courses Taught By Year

Since 1991, DAN has trained over 300,000 providers, and is approaching 40,000 instructors. Many of our courses are now available in Spanish, Portuguese, and French. Future languages will include Chinese, Korean, and others.

DAN Training plays a vital and multi-faceted role in the mission to make every dive free of incidents and accidents. This is accomplished by focusing on first aid programs, and expanding the role of other departments within DAN to contribute to safety education As a result, DAN now offers a wide array of courses designed to improve the knowledge and preparedness of non-divers and divers alike, regardless of experience level.

In 2021, DAN revised many of the first aid courses to meet the updated ILCOR guidelines. We refer to the changes to the various courses collectively as Version 3.0, which include some significant changes, some tweaks, and some things that remain unchanged. All courses have some updated videos in e-learning as well as updated graphics, images, and slates. In some cases the layout of material was revised as well.

Version 3.0 course offerings are more streamlined than V2.1. The V3.0 courses include DAN CPR and First Aid (BLS), Emergency Oxygen for Scuba Diving Injuries (EO2), and Diving First Aid for Professional Divers (DFA Pro). Neuro and HMLI are included only as part of DFA Pro now. It was also decided that DEMP would not be continued in Version 3.0. These decisions were made due to shift the focus to our top three courses: EO2, DFA Pro, and BLS.

DAN CPR AND FIRST AID (BLS)

We took the BLS and HCP courses and merged them together; this makes for a more robust course. Now the Version 3.0 BLS course includes 1- and 2-rescuer CPR, AEDs, and three methods for addressing Foreign Body Airway Obstructions (FBAO): abdominal thrusts, chest thrusts, and back blows for adults and children. The first aid section now includes new and enhanced information and skills pertaining to: wound packing; dislocations; amputations; internal bleeding; open chest wounds; and spinal injury management. Other first aid skills from Version 2.1 were unchanged.

EMERGENCY OXYGEN FOR SCUBA DIVING INJURIES (EO2)

This course has the fewest changes and remains our “flagship” first aid course. The only significant changes to the EO2 course are updated graphics, images, and videos in e-learning.

DIVING FIRST AID FOR PROFESSIONAL DIVERS (DFA PRO)

This course, like past versions, incorporates all the knowledge, skills, and materials from the other courses (BLS and EO2) and adds Neurological Assessment and First Aid for Hazardous Marine Life Injuries. DFA Pro is designed for commercial, professional, aquarium, and scientific divers, and it provides knowledge and first aid skills specifically for these work environments. It is the most comprehensive first aid course in the dive industry, and taking this course gives divemasters and instructors an indispensable set of risk mitigation skills.

While all these courses are either diving-focused or use diving in many of the examples and training scenarios, all courses are available to the general public, not just the diving community.

If you would like to know more about DAN’s first aid programs, wish to take one, or even become an instructor with DAN, please visit **dan.org/education-events/instructor-led-courses/**

OTHER SAFETY PROGRAMS

The Training and Education team has also collaborated with DAN’s Risk Mitigation Team to develop several new free e-learning courses that cover a variety of topics. They are:

- Emergency Planning for Divers
- Emergency Planning for Dive Operators & Professionals
- HIRA (Hazard Identification Risk Assessment) Level I for Dive Businesses
- HIRA Level I for Dive Professionals
- HIRA Level II for Dive Businesses
- HIRA Level II for Dive Professionals
- Environmental Stewardship for Divers

These courses are available free of charge at **dan.diverelearning.com**. If you do not already have a DAN e-learning profile, you will be asked to create one.

DAN Safety Services, which includes DAN Training, strives to help make every dive an incident and accident free dive, while empowering and training divers and dive professionals with the tools needed to assist if something unfortunate occurs.

If there are specific questions about DAN Training, don’t hesitate to contact us at 919-684-2948 option 2 or at **oxygen@dan.org**.

APPENDIX C.
RESEARCH HIGHLIGHT: CARDIAC HEALTH IN DIVING

INCIDENCE OF CARDIAC ARRYTHMIAS AND LEFT VENTRICULAR HYPERTROPHY IN RECREATIONAL SCUBA DIVER

Peter Buzzacott, George Anderson, Frauke Tillmans, James Grier, Petar Denoble

INTRODUCTION

Scuba diving has many well-established risks including but not limited to DCS, barotrauma, oxygen toxicity, and gas embolisms. Cardiac events are an often overlooked risk factor although they contribute to almost one-third of all recreational scuba fatalities.[1,2] Many of these cardiac deaths can be classified as sudden cardiac death (SCD). SCD is defined as an unexpected natural death from a cardiac cause that occurs within one hour of symptom onset in people with no underlying conditions that would appear fatal.[3] While myocardial infarctions (MIs) and coronary artery disease are the most common cause of SCD on land, cardiac arrest due to acute dysrhythmia is the most common suspected mechanism of SCD while diving.[4]

SCD is still poorly understood although there are a few known risk factors including: a history of coronary heart disease; cigarette smoking; hypertension; diabetes mellitu; hypercholesterolemia; obesity; left ventricular hypertrophy; male sex; and age. The activity of diving in particular may affect the likelihood that a diver may experiences SCD; immersion and exercise increase stress on cardiopulmonary and autonomic function. These stressors may trigger or exacerbate existing dysrhythmia.

Left ventricular hypertrophy (LVH) is an independent risk factor for SCD. It is defined as an abnormal increase in mass of the left ventricular walls as a response to increased workload. This workload may be caused by high blood pressure or aortic stenosis.

Movement underwater also increases demand for oxygen which induces increased cardiac output. The increased ambient pressure experienced while diving also causes a blood shift from peripheral vasculature to the thoracic cavity further stressing the cardiovascular system which may alter the incidence of arrythmias and by extension, SCD.

CURRENT RESEARCH

DAN'S LVH STUDY

DAN's research department has been working to understand the prevalence of possible risk factors of disabling cardiac conditions in diving including arrhythmias and arrhythmogenic structural changes like LVH. An improved understanding of these risk factors allows us to provide better guidance for an aging dive population who are at greater risk for cardiac events.

To study the prevalence of these cardiac risk factors, data was collected from 77 certified divers over 40 years old who participated in 84 dive trips and 677 recorded dives. Pre- and post- dive trip electrocardiograms (ECG) and echocardiograms were collected and analyzed for the presence of arrythmias and LVH.

Arrhythmias were identified in ECGs of 37% of participants; this represents a higher frequency than observed in the general public. One study found arrythmias were identified in 13% of an elderly population in Sweden (mean age 74 years).[5] Another study found arrythmias in only 2% of middle-aged to elderly adults in the UK (mean age 58 years).[6] When comparing participants in our study against each other, we found that on average, divers who recorded at least on pre-trip arrhythmia were more likely to record a post-trip arrhythmia. However even among divers without pre-trip arrhythmias, one in nine divers recorded post-trip arrhythmias. Analysis of echocardiogram data showed that the prevalence of LVH in this cohort of divers (8%) was similar to that observed in a Norwegian control group,[7] but was much lower than the 31% found in the autopsies of 100 recreational divers.[8] This suggests that LVH may have a significant impact in diving fatalities.

This study was closed in fall 2020, and results were published in the Undersea and Hyperbaric Medicine Journal in 2021.[9]

NEXT STEPS AND OTHER PROJECTS

The link between SCD, arrythmias, and LVH are still unclear, but DAN is currently tackling this as well as other issues with continued research. Further cardiac research is currently being performed currently in collaboration with public safety divers of all ages to determine if the extra occupational exertion has any additional effects on cardiac health. Other cardiac health related projects are underway investigating the application of underwater cardiac monitoring devices in research.

In honor of Dr. Alfred Bove, a diving physician, cardiologist and valued collaborator of DAN for many decades, the DAN Research Grant Program awards up to $50,000 per year to fund projects related to cardiac health and diving.

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APPENDIX D. PUBLICATIONS 2018

Jeanette Moore

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APPENDIX E. PRESENTATIONS 2018

Jeannette Moore

Burman F. International ATMO safety director, acrylics and hyperbaric facility maintenance courses. San Antonio, TX. January 15–20, 2018.

Burman F. DAN Diving safety officer course. DAN Headquarters, Durham, NC. January 25–30, 2018.

Nochetto M. Our World Underwater Dive & Travel Show. Chicago, IL. February 17–18, 2018.
The perils of artisanal divers in the Americas
Remote operations injury management

Chimiak J. SAR presentation. Charleston, SC. March 2, 2018.

Seery PL. Examiner workshop. DAN Headquarters, Durham, NC. January 26–28, 2018.

Buzzacott P. DAN Research into diving incidents and the safety of nitrox. North Shore Frogmen, Boston, MA. March 8, 2018.

Buzzacott P. The frontier of decompression research. Boston Sea Rovers, Boston, MA. March 11, 2018.

Chimiak J. Safety at sea. USNA, Annapolis, MD. March 24, 2018.

Buzzacott P. Beneath the Sea, Secaucus, NJ. March 24, 2018.
Frontier of decompression research
The DAN annual diving report
Lessons from 500 diving incident reports

Nochetto M. Beneath the Sea, Secaucus, NJ. March 24, 2019.
Delta P and barotrauma: what pressure can do to gas filled spaced.
Cases from the DAN emergency hotline
Recompression therapy: one does not just squeeze bubbles

Buzzacott P. Evidence-based diving safety. Duke University, Durham, NC. April 4, 2018.

Buzzacott P. Using the BRFSS to characterize adult US Scuba divers. CDC BRFFS Training Workshop. Atlanta, GA. April 9–13, 2018.

Seery PL. Instructor trainer update into eLearning and new course methodology (DAN and NAUI Trainers). Sao Paulo, Brasil. April 8–15, 2018.

Sorrell L. Stuff happens — now what? The Blue Wild, Ft. Lauderdale, FL. April 14–15, 2018.

Buzzacott P. TechDive USA. Orlando, FL. April 27–29, 2018.
Cave diving fatalities monitoring and prevention
Tech diving near misses, injuries and fatalities in the DAN database

Sorrell L. Defining dive safety. Villages Scuba Club, The Villages, FL. May 02, 2018. (webinar)

Sorrell L. Medications & diving. Blue Dolphins Skin Diving Club, Erie, PA. May 3, 2018. (webinar)

Seery PL. Internal DAN staff - Instructor Trainer Workshop.
DAN headquarters, Durham, NC. May 16–18, 2018.

Buzzacott P. First 500 incident reports. Rum Runner Dive Club meeting. May 21, 2018.

Burman F. DAN Diving safety officer course. DAN, Durham, NC. May 21–25, 2018.

Burman F. The Dive safety officer course. Braine-l'Alleud, Belgium. May 27–June 01, 2018.

Buzzacott P. International Extreme Sports Medicine Congress, Boulder, CO. June 1–2, 2018.
Pediatric and adolescent injury in aquatic adventure sports
Medical aspects of world record scuba dives — deep water and high altitude
Free diving — injuries and fatalities in the quietest of extreme sports

Denoble PJ. Decompression stress. DAN Interns Training, Durham, NC. June 1, 2018.

Buzzacott P. Frontiers of decompression research. DAN Public Lecture, Durham, NC. June 6, 2018.

Burman F. Diving and hyperbaric safety course. Simon Frazer University, Vancouver, Canada. Jun. 8–9, 2018.

Burman F. International ATMO Safety Director, Acrylics and Hyperbaric Facility Maintenance courses.
San Antonio, TX: June 14–19, 2018.

Buzzacott P. Scuba Show, Long Beach, CA. June 22–23, 2018.
High altitude "fizziology"
30 Years of the DAN annual diving report

Burman F. Scuba Show. Long Beach, CA. June 22–23, 2018.
Customizing your emergency action plan
DAN HIRA: The risk assessment and mitigation program

Nochetto M. Scuba Show. Long Beach, CA. June 22–23, 2018.
Delta P and barotrauma: what pressure can do to gas filled spaced
Recompression therapy: one does not just squeeze bubbles

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Estimated workload intensity during volunteer aquarium dives
Self-reported recreational scuba diving incidents — analysis of 500 cases

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Nochetto M. DAN/UHMS Diving and Hyperbaric Medicine. Anse Chastanet, St. Lucia. September 8–15, 2018.

Gax toxicities
Remote operations injury management
Case studies
Parasitic infections in dive travel

Burman F. International ATMO Safety Director, Acrylics and Hyperbaric Facility Maintenance courses. San Antonio, TX: September 17–21, 2018.

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Sorrell L. An exercise in critical thinking a look at case studies and emergency preparedness through the eyes of dive professionals. Cozumel Seminars, Cozumel, MX. October 09, 2018.

Burman F. A risk-based approach to recompression chamber safety. DAN Divers Day. Galatasaray University. Istanbul, Turkey. October 14, 2018.

Burman F. Safety concerns in the diving industry: a culture of safety. DAN Divers Day. Istanbul, Turkey. October 14, 2018.

Burman F. Hyperbaric safety management course. Istanbul Public Hospital. Turkey. October 16, 2018.

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Tillmans F. Top 3 most annoying medical problems for diving professionals. 25th Anniversary of the Hyperbaric Chamber in Sharm El Sheikh. Egypt. November 3, 2018.

Tillmans F. The bumpy road to personalized decompression. 25th Anniversary of the Hyperbaric Chamber in Sharm El Sheikh. Egypt. November 6, 2018.

Buzzacott P. 30 Years of the DAN Annual Diving Report. 2018 British Hyperbaric Association Annual Scientific Meeting. London, UK. November 8–9, 2018.

Buzzacott P. Frontiers of decompression research. 2018 British Hyperbaric Association Annual Scientific Meeting. London, UK. November 8–9, 2018.

Burman, F. The Diving Equipment and Marketing Association (DEMA) Show 2018
Las Vegas, NV. November 10–14, 2018.

Common safety concerns in dive businesses: are you really prepared?
Risk mitigation for the safety-conscious dive operation: a systematic approach
Will my emergency plan work when I need it?

Denoble PJ. The Diving Equipment and Marketing Association (DEMA) Show 2018.
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Conditions that physicians and divers may confuse for diving injury
Research advances in breath-hold diving

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Do child divers get injured? Injury management in remote locations

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The top three annoying medical problems for dive professionals
Cold-water diving — challenges and rewards for suffering the cold
The bumpy road to personalized decompression: Where are we headed?
Women and diving — equal opportunity vs. physiology

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6 West Colony Place
Durham NC 27705 USA

CUSTOMER SERVICE
+1 (919) 684-2948

DAN EMERGENCY HOTLINE
+1 (919) 684-9111

WEBSITE
DAN.org

EMAIL
member@dan.org

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