Scuba diving injuries among Divers Alert Network members 2010–2011

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Abstract

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Background: Scuba diving injuries vary greatly in severity and prognosis. While decompression sickness (DCS) and arterial gas embolism can be tracked easily, other forms of diving injury remain unaccounted for.

Purpose: The purpose of this paper is to assess rates of overall self-reported scuba-diving-related injuries, self-reported DCS-like symptoms, and treated DCS and their association with diver certification level, diving experience and demographic factors.

Methods: We analyzed self-reported data from a Divers Alert Network membership health survey conducted during the summer of 2011. Poisson regression models with scaled deviance were used to model the relative rates of reported injuries. Models were adjusted for sex, age, body mass index (BMI) and average annual dives, based on the bias-variance tradeoff.

Results: The overall rate of diving-related injury was 3.02 per 100 dives, self-reported DCS symptoms was 1.55 per 1,000 dives and treated DCS was 5.72 per 100,000 dives. Diving-related injury and self-reported DCS symptom rates decreased for higher diver certification levels, increasing age, increasing number of average annual dives and for men; they increased for increasing BMI.

Conclusions: Diving injury rates may be higher than previously thought, indicating a greater burden on the diving community. Self-reported DCS-like symptoms are a small fraction of all dive-related injuries and those receiving treatment for DCS are an even smaller fraction. The small number of divers seeking treatment may suggest the mild nature and a tendency towards natural resolution for most injuries.

Key words

Injuries, decompression sickness, epidemiology, health survey, DAN – Divers Alert Network, recreational diving

Introduction

Scuba diving is a popular recreational activity, which occurs in an unforgiving environment. It is associated with known hazards related to interaction with the marine environment, complex equipment, physical limitations and the human element. Injuries are not uncommon but fatalities are rare. There were about 2.5 million scuba divers in the United States in the year 2000.[1] The lower age limit of divers is 12 years, but there is no upper age limit. Data from the United States and Japan indicate that the scuba diving population is ageing.[2,3] The decline in physical capacity and encroachment of chronic diseases with increasing age may increase diving-associated injuries and fatality rates.

Diving injuries range from mild to fatal. They may be diving-specific like ear barotrauma, decompression sickness (DCS) and arterial gas embolism (AGE), or non-specific, like trauma, envenomation, etc. While a reporting system for diving injuries that provides reliable injury data for comparison with other sports does not exist[4], Divers Alert Network (DAN), the world's largest scuba divers' membership organization, monitors fatalities in the USA and Canada through media outlets and sometimes by requesting access to autopsy and accident reports. A separate ongoing study by DAN Asia Pacific (previously known as *Project Stickybeak*, which had reported Australian diving-related fatalities since the early 1970s) continues to report annually.[5] The number of fatalities in North America varies between 80 and 90 deaths per year.[6] Based on the DAN AP reports (not including snorkelling deaths), the number of fatalities in Australia during 2000 to 2009 averaged 10 deaths per year.[5] An analysis of DAN insurance claims data estimates the rate of diving fatalities at 16.5 per 100,000 person-years.[7]

The literature on overall diving-related injuries is sparse.[8] DCS and AGE may be tracked through hyperbaric treatment records, while other injuries remain largely unaccounted for. In terms of cost from diving-related injuries, severe DCS, AGE, and fatalities cause the most loss to victims and their families and bear the highest costs of evacuation, treatments and/or repatriation. Other less severe diving-related injuries are usually less costly to treat; however, they are so much more common that the treatment costs and days of productive life lost may amount to a significant burden to the diving community. In August 2011, we conducted an online survey among DAN members that sought to investigate diving-related behaviour and the incidence of diving injuries. This paper explores the relationship between diver demographics, certification, and scuba-diving injuries.

Methods

A DAN membership health survey was administered online as a two-part cross-sectional survey. The survey comprises 20 sections and is too large to be reproduced here; a copy

may be obtained from the corresponding author upon request. One part comprised several modules from the Behavioral Risk Factor Surveillance System (BRFSS) investigating the health status of divers, which will be reported separately.[9] The other part was a survey about diving practices and injuries, a slightly modified version of a survey conducted among dive instructors in Sweden.[10] The original survey was validated, and has been described by the authors.[10] We adjusted this survey for the DAN population by adding options and additional questions applicable to a general diving population. Doing so, we went through multiple phases of critical review by dive medicine experts, instructors, dive medicine technicians and divers. It was piloted among 15 divers for face validation; that is, to see if the respondents understood the questions and answered them appropriately. We randomly selected 30,000 of a little over 150,000 DAN members and invited them to participate via e-mail. Only invited divers had access to the survey and they could respond only once. On-line consent was obtained, which informed the participants that they had to be 18 years of age or older and must have dived at least once during 2010/2011 to be able to participate; if ineligible, they were asked to exclude themselves. Unless they requested exclusion or completed the survey, invitees were reminded three times by weekly e-mails. There was no follow up and the survey was open for two months. No identifying information was collected. This study was approved by the Divers Alert Network (IRB # 001-11, 08 February 2011; re-approved 2012 and 2013).

This retrospective survey focused on participant diving exposures and diving-related injuries in the preceding twelve months over 2010/2011. It also included the number of hyperbaric treatment(s) received or advised for corroborating the diagnosis of DCS. However, some mild cases of DCS may not be identified and/or receive treatment. In an attempt to capture potentially undiagnosed DCS cases, we identified self-reported DCS-like symptoms irrespective of their treatment or referral status to a hyperbaric facility. Self-reported DCS-like symptoms included: loss of muscular strength (paralysis) after diving, skin rash or marbling up to several hours after diving and pain in joints or muscles after diving. The respondents reported their diving-related injuries and the number of dives cumulatively over one year; hence the estimated injury rates from these aggregated data are ecologic in nature.

STATISTICAL METHODS

Descriptive statistics of the collected variables are discussed using tables and frequencies. Body mass index (BMI) was calculated using the self-reported weight and height from the survey and was classified as normal (< 25 kg m^{-2}), overweight (25–30), and obese (> 30).

Injury rates were calculated for self-reported dive-related injuries, self-reported DCS-like symptoms, and treated DCS using Poisson regression models with scaled deviance among divers with different diving certification levels (basic, advanced, instructor). These rates were adjusted for sex, average annual dives, BMI and age, based on change in estimate and bias-variance tradeoff.[11] Specifically, a covariate was retained in the model if the change in the estimated variance of the diving certification level coefficient was negative upon adjustment for that covariate or positive but smaller than the squared change.

Self-reported injury rates were expressed per 100 dives. We excluded seasickness from the rate calculations because high turbulence in the sea may lead to motion sickness in almost all occupants of a boat.[12] The self-reported DCS-like symptom rates were expressed per 1,000 dives and the rate of treated DCS was reported per 100,000 dives. Rates were compared for different diving certification levels (basic, advanced, and instructor), sex (female and male), 10-year increments in age, BMI categories (normal, overweight, and obese) and 20-dive increments of average annual dives.

Two-sided Student's *t*-tests were used to compare the age distribution of 'respondents' to that of 'invitees' and to compare the percentage of specific injuries between males and females. We used the Mantel-Haenszel chi-square test to compare the sex distribution of respondents to that of invitees. The SAS 9.3 statistical package (SAS Inc, Cary, NC) was used for descriptive statistics, *t*-tests, Mantel-Haenszel chi-square test, and Poisson regression analyses.

Results

Out of the invited 30,000 DAN members, 18.4% ($n = 5,514$) responded to the survey, and 16.2% ($n = 4,859$) submitted all 20 survey sections. The respondents who did not submit all the sections of the survey, maybe owing to internet failure or unwillingness to answer the survey any further, were considered self-withdrawn.

The median age of respondents was 52 (range 18–90) years. The mean BMI was 26.9 ± 4.51 $kg \cdot m^{-2}$ (21% obese, 42% overweight, and 37% normal) (Table 1). We compared the age and sex distribution among invitees to the demographic distribution of respondents. The invitee population comprised 74.1% males, and respondents 73.5% males ($P = 0.47$). The mean age of invitees was 48.1 years and that of respondents was 50.2 years, a mean age difference of 2.1 years ($P < 0.001$). This indicates that those who completed the survey were, on average, older than the DAN population.

DIVING PRACTICE

The majority of the divers had advanced level certifications (63%), followed by basic (20%) and instructor level certifications (17%). Respondents made a total of 174,912 dives in the preceding year, mostly performing between 1 and 100 dives (95.7%; median 20 dives, mean 37 dives,

Table 1
Characteristics of the participants by diver certification level; missing values in the table refer to the missing data for diver certification level of the respondents

	Diver certification level									
Variable	Basic		Advanced		Instructor		Missing		Total	
Sex*	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Male	573	65.0	2,080	73.9	655	82.0	80	71.4	3,388	73.5
Female	308	35.0	735	26.1	144	18.0	32	28.6	1,219	26.5
BMI†										
Normal	326	39.1	1,047	37.7	238	30.4	78	54.5	1,689	37.3
Overweight	333	40.0	1,178	42.4	352	45.0	46	32.2	1,909	42.1
Obese	174	20.9	551	19.8	192	24.6	19	13.3	936	20.6

* 252 participants did not provide sex information
† 325 participants did not provide height and/or weight information

Table 2
Self-reported diving-related injuries by participant's sex; * $P < 0.05$; male vs. female

	Males *n* (%)		Females *n* (%)		Missing *n* (%)		Total *n* (%)	
Ear problems (other than hearing loss)*	733	(19.9)	371	(21.7)	76	(16.1)	1,180	(20.1)
Headache*	543	(14.7)	285	(16.7)	78	(16.6)	906	(15.4)
Sinus troubles	425	(11.5)	180	(10.5)	50	(10.6)	655	(11.2)
Puncture wound, laceration	375	(10.2)	110	(6.4)	43	(9.1)	528	(9.0)
Overexertion, low back pain, sprain/strain*	290	(7.9)	155	(9.1)	52	(11.0)	497	(8.5)
Mask squeeze	302	(8.2)	142	(8.3)	46	(9.8)	490	(8.4)
Pain in joints and/or muscles[1]	175	(4.7)	66	(3.9)	15	(3.2)	256	(4.4)
Itching after diving (< 20 min)	140	(3.8)	66	(3.9)	6	(1.3)	212	(3.6)
Allergic contact dermatitis*	86	(2.3)	103	(6.0)	14	(3.0)	203	(3.5)
Tooth pain	98	(2.7)	30	(1.8)	14	(3.0)	142	(2.4)
Hearing loss	84	(2.3)	36	(2.1)	16	(3.4)	136	(2.3)
Dizziness/giddiness	81	(2.2)	35	(2.0)	13	(2.8)	129	(2.2)
Skin rash/marbling (several h)[2]	79	(2.1)	40	(2.3)	10	(2.1)	129	(2.2)
Dyspnoea	71	(1.9)	21	(1.2)	8	(1.7)	100	(1.7)
Animal bite	55	(1.5)	31	(1.8)	10	(2.1)	96	(1.6)
Crushing injury/fracture*	64	(1.7)	8	(0.5)	6	(1.3)	78	(1.3)
Burns	37	(1.0)	15	(0.9)	4	(0.8)	56	(1.0)
Ankle sprain	31	(0.8)	13	(0.8)	5	(1.1)	49	(0.8)
Loss of muscular strength/ (paralysis)[3]	14	(0.4)	1	(0.1)	1	(0.2)	16	(0.3)
Unconsciousness	3	(0.1)	0	(0)	4	(0.8)	7	(0.1)
Total*	3,686		1,708		471		5,865	
Decompression sickness (1+2+3)	192		73		17		282	

[1, 2 and 3] – total self-reported DCS symptoms were computed by combining three symptoms: pain in joints and/or muscles, skin rash or marbling (several hours), and loss of muscular strength (paralysis)

range 1–300 dives). Those who performed more than 100 dives per year were predominantly advanced- and instructor-level divers. The mean and median number of dives was similar for divers of all age groups except for 75 and over, who dived less. Respondents engaged in various types of diving: wreck dives (64.6%), night dives (65%), cave dives (11.4%), planned decompression dives (16.2%), rebreather dives (2.3%), nitrox dives (49.2%), ice dives (4.1%), cold water dives (41%), altitude dives (9.9%), and dives for repair work (8.6%). Over 60% of divers reported diving in low visibility and about 44% reported diving in strong currents.

INJURIES

A total of 5,865 diving-related injuries were reported by 1,580 (32.5%) respondents regardless of whether they

Table 3
Adjusted rate ratios (95% confidence interval) for all injuries, DCS-like symptoms and treated DCS, adjusted for sex, BMI, average annual dives, and diving certification; and overall rates per 100,000 dives for all injuries, DCS-like symptoms and DCS

Variable	Category	All injuries		DCS symptoms		Treated DCS	
Diver certification level	Advanced	0.78	(0.65–0.92)	0.79	(0.62–1.01)	–	
(reference = basic)	Instructor	0.68	(0.55–0.84)	0.81	(0.60–1.10)	–	
Sex (reference = female)	Male	0.67	(0.58–0.77)	0.65	(0.53–0.79)	2.56	(1.75–3.74)
Age	10-years increase	0.89	(0.85–0.94)	0.90	(0.84–0.97)	1.04	(0.95–1.14)
BMI	Overweight	1.10	(0.96–1.27)	2.12	(1.69–2.65)	–	
(reference = normal)	Obese	1.07	(0.91 –1.26)	1.97	(1.54 – 2.54)	–	
Average annual dives	20 dives increase	0.89	(0.87–0.92)	0.84	(0.80–0.88)	–	
Rate per 100,000 dives (95% CI)		3,024	(2,845–3,214)	155	(142–169)	5.72	(5.11–6.39)

*Adjusted for sex, BMI, average annual dives, and diving certification level

received treatment or not. Injuries requiring treatment were reported by 665 (13.7%) respondents; 38 (5.7%) of these respondents claimed insurance. Eleven divers (0.2%) received 18 recommendations for hyperbaric oxygen treatments and in 16 instances this advice was followed. Table 2 shows the proportion of each self-reported diving injury. Ear problems other than hearing loss were the most reported. DCS-like symptoms were reported by 282 respondents (5.8%).

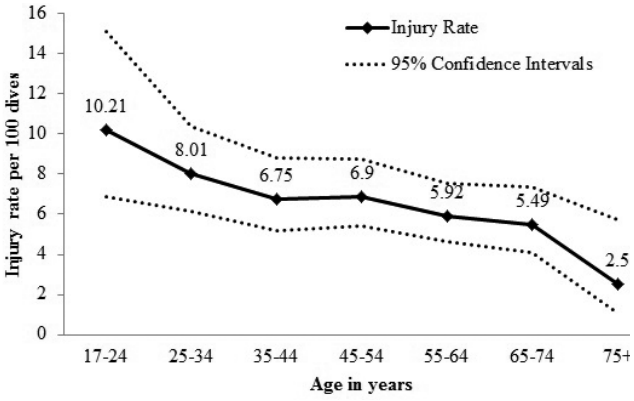
INJURY RATES

The crude rate for all diving-related injuries was 3.02 per 100 dives (95% confidence intervals (CI) 2.85 to 3.21). The adjusted injury rates decreased with increasing age (Figure 1). The crude injury rate for males was 2.65 per 100 dives (95% CI 2.46 to 2.85) and for females was 4.30 per 100 dives (95% CI 3.87 to 4.79), giving a crude male-to-female rate ratio of 0.62 (95% CI 0.54 to 0.70). From Table 3, the adjusted injury rate ratio for males as compared to females was 0.67 (95% CI 0.58 to 0.77).

The overall crude self-reported DCS-like symptom rate was 1.55 per 1,000 dives (95% CI 1.42 to 1.69). Higher diver certification level was associated with a monotonic decrease in all dive-related injuries (Table 3). Compared to basic certification divers, the adjusted rate ratio of all dive-related injuries for instructor divers was 0.68 (95% CI 0.55 to 0.84), and for advanced divers was 0.78 (95% CI 0.65 to 0.92). We considered the diagnosis of DCS confirmed in the 11 respondents who received hyperbaric oxygen treatment (16 treatments). After taking into account multiple treatments for two divers, the DCS incidence rate was 5.72 per 100,000 dives (95% CI 5.11 to 6.39).

Table 3 also shows the comparison of rates between self-reported diving injuries, self-reported DCS-like symptoms, and treated DCS cases by using a common denominator of

Figure 1
Adjusted self-reported injury rates by age of the participants, adjusted for sex, BMI, average annual dives, and diving certification level



100,000 dives. Thirty-seven per cent of respondents reported diving-related injuries, compared to 4% reporting DCS-like symptoms, and 0.23% receiving hyperbaric treatment. This implies that the incidence rate of all diving-related injuries is almost 20 times greater than the incidence of DCS-like symptoms. Furthermore, the incidence rate of DCS-like symptoms was over 25 times greater than treated DCS cases.

We also compared the injury rates of those who logged their dives (84%) versus those who did not (16%). Divers who log their dives reported fewer injuries (mean 1.15 per person) than those who do not log their dives (mean injuries 1.54). Also, those who log their dives reported fewer dives (mean = 32) during the survey period compared to those who do not log their dives (mean = 47). Consequently, the crude rate ratio of injuries for those who log their dives versus those who do not is 1.09 (95% CI 0.95, 1.25). The adjusted rate ratio for those who log their dives versus those who do not is 1.10 (95% CI 0.95, 1.25).

Discussion

SELF-REPORTED DIVING INJURIES

The crude overall self-reported diving injury rate was 3.02 per 100 dives. The most common injuries included ear troubles, headaches, and sinus troubles. Headache, although not a specific symptom of a dive injury, may be observed in cases of DCS, AGE, sinus or ear barotrauma and carbon dioxide retention. Thus it was included in dive-related injuries but because of unknown context it was not accounted for as DCS-like symptoms.

The higher injury rates amongst 17–24 year-olds compared to older divers could be explained by older divers being more experienced and diving more conservatively. We have no clear explanation for the higher injury rate amongst women compared to men. The inverse relationship between certification level and injury rate could be expected as divers with higher certification levels should have learnt better skills. The only previous study to have reported on all diving-related injuries found much lower rates ratios – 0.56 per 100 dives in 1999 and 0.98 per 100 dives in 2000 – than we have reported in this study.[8] However, they obtained the injury information from dive operators rather than from divers, and the number of dives was calculated based on the number of tanks used.[8]

DECOMPRESSION SICKNESS

The crude incidence of self-reported DCS-like symptoms was 1.55 per 1000 dives. Men reported 35% fewer DCS-like symptoms than women, whereas, when considering treated-DCS rates in our survey, that in men was 2.56 times higher than in women. In the Swedish study, no such effect of sex on DCS symptoms was evident.[10] Men may have a tendency to perform more extreme dives, which lead to more severe cases that need treatment. This observation is supported by other studies which report higher incidence of treated DCS rates in men than in women.[2,13]

Insurance claims data for DCS suggest that the incidence of DCS claims decreases with increasing age, which corroborates our results.[2] This may be attributed to conservative diving habits in older divers; however, this explanation may be inadequate because older divers have higher rates of diving fatalities.[7]

The treated-DCS incidence rate based on our self-reported data was 5.72 per 100,000 dives. This is considerably less than the previously reported incidences of DCS (20 per 100,000 dives in 1999 and 46 per 100,000 dives in 2000) in Orkney, known for deep decompression diving, unlike most recreational diving.[8] These results are also lower than those from a prospective study conducted in Canada for 14 months between 1999 and 2000, in which the estimated decompression illness incidence was 9.57 per 100,000 dives.[14] Both the above-mentioned studies were prospective in nature, and were conducted more than a decade before our study.

Few studies have evaluated self-reported data for scuba -iving-related injuries. Other studies that used a questionnaire evaluated only DCS and did so based on confirmed cases.[13] Only one other study determined the incidence of self-reported symptoms of DCS to be 1.52 per 1,000 dives, for which the diver may or may not have sought medical help.[10] This is similar to our estimate of 1.55 per 1,000 dives. In both reports, skin DCS symptoms were reported more often, unlike reports of treated DCS which carry only a small percentage of skin DCS. Advanced training and age resulted in lower incidence rates of DCS symptoms in the Swedish study.[10] Similar effects of lowered DCS incidence for divers with higher certification levels have been noted by others.[15] The results of our survey are consistent with these data.

In our study, the overall self-reported DCS-like symptom rate was over 25 times higher than the rate of treated DCS. This suggests the presence of mild symptoms of DCS that resolved spontaneously. This is supported by a 1993 Norwegian study of commercial and sports divers in which about 19% of sports divers, 50% of commercial air divers, and 63% of saturation divers reported DCS-like symptoms; however, only 3% of sports divers, 13% of commercial air divers and 28% of saturation divers sought hyperbaric treatment for DCS.[16] Under-reporting of DCS symptoms may be a problem for outcome-based evaluations of diving practices and safety of decompression algorithms.

The incidence of treated DCS in survey-based studies varies between 5 and 30 cases per 100,000 dives.[13,17–19] Field studies reporting DCS incidence rates among smaller diving populations range from 10 to 20 cases per 100,000 dives.[20–22] Navy divers have a similar or higher incidence of DCS compared to recreational divers.[21–23] This variability is small and largely owing to the difference in study populations and their diving practices.

DIVING EXPERIENCE

Diving experience affects dive safety and risk of injury, but it is difficult to quantify. A diver who has dived for many years may be considered more experienced although, in most sports, experience is usually defined as the number of games played in a lifetime. Using lifetime dives would be a better metric to represent diving experience; however, both these metrics fail to account for the frequency of diving. A diver who dives five times a year for 20 years will be considered less experienced than a diver diving 50 dives a year for 2 years. Hence, annual dives may represent diving experience better than number of years diving or lifetime dives. In our analysis we found that an increase of 20 average annual dives was associated with 11% fewer diving injuries and 16% fewer DCS-like symptoms.

LIMITATIONS

We used a survey that was developed for diving instructors and made adjustments to it for a general diving population. The demographic data were collected using questions from the BRFSS.[9] Our survey used these two well-validated surveys with only minor modifications; however, it was not validated in multiple groups of divers. Instead, our survey underwent multiple reviews by diving experts, and we pilot-tested it among a small group of 15 divers for face validation.

Determining incidence rates of diving injuries and DCS remains a challenge because of differences in demographics and diving practices amongst various subgroups. DAN's membership population is composed of divers who are older and more active than the general scuba-diving population, but their diving practices reflect overall practice of that population. In addition, at present, DAN's membership may be the best-known, defined diver population for such a study. However, a longitudinal study would establish injury incidence more reliably. The findings from our study may not be generalizable, but they are indicative of similar trends in the general diving population.

The retrospective study design introduces recall bias and may affect the reliability of the study. There were 1,580 divers who reported symptoms consistent with diving injury, but only 665 sought medical help. There is a chance that the divers may have over-reported or under-reported the frequency of symptoms. It may be assumed that those who log their dives may have better recollection of post-dive symptoms than those who do not. However, there was no difference in the crude and adjusted injury-rate ratios between the two groups.

Ecological analyses limit our interpretation of results, which may be prone to ecological fallacy. By this we mean that we collected diver-level data (the number of dives and the number of symptoms), not dive-level data (depth, time underwater, breathing gas mixture, etc.), although the estimated injury rates are per-dive measures. Caution is advised in the interpretation of these estimates as dive outcomes may be affected by depth and time measures of a dive, which our study could not explore.

Conclusions

The incidence of overall dive-related injuries may be higher than previously thought, but most injuries appear to be mild. DCS-like symptoms make up only about 5% of all reported injuries. The incidence rate of the symptoms consistent with DCS (DCS-like symptoms) was 25 times higher than the incidence rate of DCS cases receiving medical evaluation. This suggests that the incidence of DCS may be higher than that which gets treated or recorded.

Rates of all diving-related injuries and DCS-like symptoms decrease with advancing age. Males report fewer diving injuries than females. Divers with advanced- and instructor-level certification report fewer injuries than basic-level divers.

Prospective cohort studies with better recording of dive exposures and better evaluation of associated outcomes, including all injuries, not only DCS and AGE, may be necessary to attain greater insight into the potential impact of diving injuries. Establishing reporting systems for all diving-related injuries and encouraging divers to report all symptoms as they occur may also yield better data. Injury-prevention strategies such as the use of pre-dive checklists, and encouraging divers to do refresher courses and to attain higher diving certification levels may target all diving-related injuries and yield better health outcomes for scuba divers.

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