Dive problems and risk factors for diving morbidity

Peter Buzzacott, Petar Denoble, Richard Dunford and Richard Vann

Key words
Diving accidents, risk factors, buoyancy, scuba diving, DAN – Divers Alert Network

Abstract
(Buzzacott P, Denoble P, Dunford R, Vann R. Dive problems and risk factors for diving morbidity. *Diving and Hyperbaric Medicine*. 2009;39(4):205-9.)
Introduction: Running out of air, buoyancy problems and rapid ascents are known risk factors for diving morbidity and mortality. The effects of the diving environment and equipment and the influence of individual diver characteristics on these risks were studied.
Methods: Between 1995 and 2004, Project Dive Exploration prospectively recorded 52,582 recreational dives made by 5,046 adult divers. Data regarding diver characteristics, dive environment, recorded depth-time profiles and reported dive problems were collected. Ascent rates were calculated from depth-time profiles. Human factors (age, sex, certification status) were tested by logistic regression for association with running out of air, buoyancy problems and rapid ascents. To control for human factors, dives where a problem was reported (case dives) were compared to dives made by the same divers in which each risk factor was not reported (control dives), again using a logistic regression model.
Results: Running out of air and buoyancy problems were significantly associated with older females, whereas rapid ascents were associated with younger males. Certification status also affected which type of problem was experienced. Maximum depth and dive time had only weak effects upon the type of problem experienced. All three problems were associated with charter boat and live-aboard diving, the most significant environmental association being the perceived workload of the dive.
Conclusions: We recommend dive instructors give greater emphasis during training to monitoring gas reserves, buoyancy control techniques and slow ascents, coupled with practical methods of gauging ascent rate. Dive boat crews should consider likely workloads when selecting dive sites and warn divers against overexertion.

Introduction

Among recreational divers, three leading causes of morbidity and mortality are drowning/near drowning, barotraumas due to expanding air whilst ascending and decompression illness (DCI), caused by the dissolution or forceful introduction of gas, forming bubbles within bodily tissues.[1–6] Running out of air, a loss of buoyancy control and making a rapid ascent have been found to be associated with these types of diving morbidity and mortality.[6–11] These risk factors are also known to occur concurrently.[11–13]

A retrospective review of 100 consecutive Australian diving fatalities separated contributing factors into three types: human, environmental and equipment.[5,14,15] Using a similar classification by dividing the data into either human (diver) or environmental/equipment (dive) characteristics, we hypothesized human characteristics would have a greater impact than environmental/equipment characteristics on the likelihood of running out of air, losing buoyancy control and/or making a rapid ascent.

Methods

Between 1995 and 2004, Project Dive Exploration (PDE) collected diver demographic data and dive profiles from recreational divers on live-aboards and day boats and/or making shore dives. Divers were approached at the commencement of a dive series at popular recreational dive sites, including in the Caribbean, Scapa Flow and Grand Cayman, and were asked to complete a survey and to record dive data after each dive. Depth-time dive profiles recorded by dive computers manufactured by Suunto, Cochran, DiveRite, Uwatec and Sensus data-loggers manufactured by ReefNet were divided into dive phases and the rate of the final ascent to the surface was calculated.[16] Ascents faster than 18.3 m.min^{-1} over at least the last 6.1 metres' sea water (msw) were classified as 'rapid'. Following each dive, divers were asked to report any problems they had experienced, selecting problems from a list. Characteristics of the dive site were recorded, such as the diving environment (e.g., ocean/river/lake) and dive platform (e.g., shore/charter boat/live-aboard). Duke University Institutional Review Board approved the protocol with a waiver of written informed consent since provision of the data implied consent. Data were checked for accuracy and false dives, for example recorded during post-dive gear washing, were removed from the dataset, leaving 56,205 dives made by 5,374 divers. A further 3,623 dives were removed (dives for training, research or commercial work, or involving trimix and rebreathers, or by children), leaving 52,582 recreational open circuit dives on air or nitrox to 40 msw or less, made by 5,046 adults.

Potential factors associated with running out of air, buoyancy problems and making a rapid ascent were classified as human (diver) or environmental/equipment (dive) factors. Human factors included age, sex, and level of dive certification.

Environmental/equipment factors included maximum depth, dive time, dive platform (shore/pier/small craft or charter boat/live-aboard), perceived workload during the dive (resting/light or moderate or severe/exhausting), exposure protection (dive-skin/wetsuit or drysuit), thermal comfort (cold/very cold or warm/pleasant), and gas breathed (air or nitrox).

A data subset of human factors was created wherein each diver was included just once and, using a logistic regression model, divers who reported running out of air, a buoyancy problem, making a rapid ascent or who recorded a rapid ascent during at least one dive were compared to divers who did not report or record those events. To then control for these human factors, four more data subsets were created wherein each dive was included where a diver had reported running out of air, a buoyancy problem, making a rapid ascent or where a diver recorded a rapid ascent (case dives), and also included in each subset were dives where the same divers did not report or record these events (control dives). Divers who made only dives during which a risk factor was reported, or who made only dives during which no risk factors were reported, were excluded from the four matched-control data subsets. Therefore, the resulting four subsets each contained only dives made by divers who had both reported or recorded at least one of the dive problems and who had also made dives where no problem was reported or recorded.

STATISTICS

Data were managed using Microsoft Access and analysed using SAS (Cary, NC), version 9.1. A logistic regression model was fitted to human factors variables by backwards elimination and variables with $P > 0.05$ were removed. Dive differences between case dives and matched control dives in the four environmental/equipment subsets were also tested by logistic regression and accepted at $P \leq 0.05$.

Results

The human factors data subset contained 5,046 adult recreational divers. Of those, complete data was obtained for 4,711 (93%) regarding age, sex, and diver certification level. Running out of air was reported by 65 of those divers (1.4%), problems with buoyancy by 223 divers (4.7%) and making a rapid ascent by 235 divers (5.0%). Dive profile loggers and personal dive computers also recorded 181 divers (3.8%) who ascended at least once by 6.1 msw or more at a rate greater than 18.3 $m.min^{-1}$. Certifications were collapsed to three levels: basic, advanced open water diver, and specialty or higher. These diver characteristics are presented by risk factor in Table 1.

Of the 52,582 adult recreational dives, 46,801 (89%) had no missing data for dive depth, dive time, dive platform, diving dress, gas mixture breathed (air or nitrox), reported thermal comfort and perceived workload. As described above, one subset each was created for running out of air (n = 86/1,293 dives, 6.7%), a buoyancy problem (n = 362/3,174 dives, 11%), reporting a rapid ascent (n = 296/2,598 dives, 11%), and recording a rapid ascent (n = 227/1,803 dives, 13%). Dive characteristics for each risk factor are presented in Table 2.

HUMAN FACTORS

Divers who reported running out of air at least once were slightly older (Odds ration (OR) per additional year 1.03, 95% CI 1.00, 1.05, $P < 0.03$) and more than twice as likely to be female as those not running out of air (OR 2.36, 95% CI 1.44, 3.86, $P < 0.001$).

Divers who reported a buoyancy problem at least once were again more likely to be female (OR 2.35, 95% CI 1.79, 3.09, $P < 0.0001$) and slightly older (OR 1.02 per year, 95% CI 1.01, 1.03, $P = 0.0036$), and also more likely to have basic diver certification rather than specialty or higher (OR 1.83, 95% CI 1.27, 2.66, $P < 0.005$).

Divers who reported making a rapid ascent at least once were slightly younger (OR per year 1.02, 95% CI 1.01, 1.03, $P < 0.001$) and more likely to have specialty or higher training (OR 3.37, 95% CI 2.3, 4.9, $P < 0.0001$).

Table 1
Human characteristics by risk factor for 4,711 divers

Variable	Running out of air (n = 65)		Buoyancy problem (n = 223)		Reporting a rapid ascent (n = 235)		Recording a rapid ascent (n = 181)		Overall (n = 4,711)	
Number male *n* (%*)	33	(51)	113	(51)	177	(75)	141	(78)	3,308	(70)
Age y (SD)	45.1	(11.9)	44.1	(11.5)	40.4	(10.4)	40.6	(11.0)	42.2	(11.1)
Certification										
Basic *n* (%)	30	(46)	112	(50)	44	(19)	90	(50)	1,916	(41)
Advanced *n* (%)	26	(40)	71	(32)	99	(42)	29	(16)	1,496	(32)
Specialty *n* (%)	9	(14)	40	(18)	92	(39)	62	(34)	1,299	(28)

* Percentages rounded to nearest whole number

Table 2
Dive characteristics by risk factor for 4,711 divers recording 46,801 dives

Variable	Running out of air (*n* = 86)		Buoyancy problem (*n* = 362)		Reporting a rapid ascent (*n* = 296)		Recording a rapid ascent (*n* = 227)		Overall (*n* = 46,801)	
Maximum depth *msw* (SD)	22.5	(8.2)	20.5	(7.3)	21.4	(7.8)	20.3	(7.0)	20.9	(7.8)
Dive time *mins* (SD)	45.8	(14.6)	45.4	(13.3)	41.1	(13.3)	33.7	(15.1)	50.9	(14.7)
Ascent rate *m.min^{-1}* (SD)	7.3	(5.9)	6.4	(7.8)	8.8	(8.1)	25.0	(9.9)	5.9	(5.2)
Dive boat *n* (%*)	77	(90)	305	(84)	273	(92)	196	(86)	40,257	(86)
Drysuit *n* (%)	5	(6)	39	(11)	198	(67)	67	(30)	5,278	(11)
Nitrox *n* (%)	14	(16)	33	(9)	105	(35)	34	(15)	9,935	(21)
Felt cold *n* (%)	7	(8)	58	(16)	60	(20)	28	(12)	4,598	(10)
Workload										
Low *n* (%)	59	(69)	223	(62)	151	(51)	154	(68)	37,706	(81)
Medium *n* (%)	20	(23)	122	(34)	102	(34)	64	(28)	8,296	(18)
High *n* (%)	7	(8)	17	(5)	43	(15)	9	(4)	799	(2)

* – Percentages rounded to nearest whole number

Likewise, divers who recorded a rapid ascent were more likely male (OR 1.45, 95% CI 1.01, 2.08, *P* < 0.05) and more likely to have specialty or higher training (OR 2.43, 95% CI 1.56, 3.82, *P* < 0.0001).

DIVING FACTORS

Dives during which divers reported running out of air were likely to have been slightly deeper (OR per msw 1.05, 95% CI 1.02, 1.08, *P* < 0.02), slightly shorter (OR per min 1.02, 95% CI 1.00, 1.04, *P* < 0.05), from a live-aboard or charter boat (OR 3.88, 95% CI 1.89, 7.94, *P* < 0.0005), and to have also reported a higher perceived workload (OR 3.72, 95% CI 1.50, 9.26, *P* < 0.005).

Dives during which divers reported a buoyancy problem were more likely to have been made from a live-aboard or charter boat (OR 1.40, 95% CI 1.03, 1.90, *P* = 0.03), to have involved air rather than nitrox (OR 2.30, 95% CI 1.57, 3.35, *P* < 0.0001), to have been reported as strenuous (OR 2.04, 95% CI 1.16, 3.60, *P* < 0.0001) and to have also been slightly shorter (OR per min 1.03, 95% CI 1.02, 1.04, *P* < 0.0001).

Dives during which a rapid ascent was reported were also more likely to be slightly shallower (OR 1.05 per m, 95% CI 1.03, 1.06, *P* < 0.0001), slightly shorter (OR 1.03 per min, 95% CI 1.02, 1.04, *P* < 0.0001), more likely from a charter boat or live-aboard (OR 1.82, 95% CI 1.14, 2.91, *P* < 0.02) and were reportedly more strenuous (OR 8.77, 95% CI 5.52, 13.89, *P* < 0.0001).

Dives during which an ascent rate of greater than 18.3 m.min^{-1} was recorded over at least 6.1 m were also more likely to be slightly shallower (OR 1.04 per m, 95% CI 1.02, 1.06, *P* < 0.0001), slightly shorter (OR 1.05 per min, 95% CI 1.04, 1.06, *P* < 0.0001), and more likely from a charter boat or live-aboard (OR 2.36, 95% CI 1.58, 3.53, *P* < 0.0001). Of the 227 recorded rapid ascents, only 28 (12%) were reported as a dive problem. An overall summary of significant associations is presented in Table 3.

Discussion

The human characteristics of age, sex and certification status appear to affect the likelihood of reporting a known risk factor for diving morbidity, and the positive or negative effect of these characteristics appears to differ between types of dive problems. Older females were more likely to run out of air or report buoyancy problems, whereas younger males ascended faster and were more likely to report a rapid ascent. Curiously, the effect of increasing certification status appears to reduce the risk of reporting a buoyancy problem yet increase the risk of ascending rapidly. That buoyancy problems were more common with low certification status was not surprising, but why higher certification resulted in ascending faster was not apparent in this study. Initially we considered the possibility that higher-certified divers were diving to deeper depths and perhaps struggling with increased volumes of air that would need to be released during ascent, but when we compared the dives where ascents were rapid to dives made by the same divers but which did not end with a rapid ascent we discovered that rapid ascents, either recorded or reported, were associated with shallower depths. We wonder now if divers are generally more attentive when diving deeper, or perhaps more carefree if they can see the surface when they commence their final ascent.

The most interesting finding though was that all four dive problems were associated with live-aboard or charter boats.

Table 3
Summary table of odds ratios by risk factor; high-cert – higher certification; low-cert – low certification

Variable	Running out of air		Buoyancy problem		Reporting a rapid ascent		Recording a rapid ascent	
Human	Female	(2.36)	Female	(2.35)	High-cert	(3.37)	High-cert	(2.43)
	Older	(1.03)	Low-cert	(1.83)	Younger	(1.02)	Male	(1.45)
			Older	(1.02)				
Environment/ Equipment	Dive boat	(3.88)	Air	(2.30)	Strenuous	(8.77)	Dive boat	(2.36)
	Strenuous	(3.72)	Strenuous	(2.04)	Dive boat	(1.82)	Shorter	(1.05)
	Deeper	(1.05)	Dive boat	(1.40)	Shallower	(1.05)	Shallower	(1.04)
	Shorter	(1.02)	Shorter	(1.03)	Shorter	(1.03)		

The weak yet significant association with shorter dive times is likely a consequence of being told when to return to the boat, but strenuous dives (when divers reported their perceived workload as "*severe*" or "*exhausting*") were strongly associated with running out of air, buoyancy problems and reporting a rapid ascent. We wonder if divers are being taken to sites they subsequently discover are more challenging than anticipated, especially older divers and females who, for example, may perceive a moderate current or long surface swim to be harder work than younger males do. Regardless of the underlying cause, we recommend dive crew advise divers before each dive to consider the potential for physical stress.

Divers wearing drysuits accounted for 11% of the 46,801 dives with no missing values, yet they accounted for 60% (*n* = 1,571) of the 2,598 dives made by divers who made both dives in which they reported ascending rapidly and also dives in which they did not. Likewise, drysuit wearers accounted for 29% (*n* = 531) of the 1,803 dives made by divers who made both dives during which they recorded a rapid ascent and dives in which they did not, which was again far more common than in the total dataset (29% versus 11%). Drysuits clearly appear to be associated with a fast rate of ascent and anecdotal free-format comments recorded on the data-collection form support such an association, yet diving dress was dropped early from each regression model. This was almost certainly because divers did not change their type of diving dress during participation in this study and so, therefore, the likelihood of ascending rapidly did not change due to diving dress. This may explain why Table 2 has such high numbers of drysuit wearers associated with reporting and/or recording rapid ascent, yet diving dress was not found to be significant.

Because data were complete for 93% of the divers and 89% of the dives, the relatively high prevalence of running out of air (1.4% of divers) and ascending faster than a commonly recommended maximum rate[17] (3.8% of divers) is in itself cause for concern, especially as the majority of those who ascended too rapidly did not report it. It is noteworthy that few people who reported a rapid ascent actually exceeded 18.3 m.min^{-1}, and few people who exceeded 18.3 m.min^{-1} later reported it as a problem. Of the 227 dives where a rapid ascent was recorded by computer, 199 (88%) were made by divers who were either unaware of their ascent rate, ascended rapidly during the dive at a time other than the final ascent, or who may have defined rapid ascent differently from the criteria used in this study. Greater emphasis upon ascent rates during training may reduce speed of ascent among divers of the future.

There were 46,801 dives with no missing data regarding environmental and equipment factors, and 86 of those (0.18%) ran out of air, 362 (0.77%) reported buoyancy problems, 296 (0.63%) reported a rapid ascent and 227 (0.49%) recorded a final ascent faster than 18.3 m.min^{-1} over at least 6.1 msw. At first glance the prevalence of these problems appears relatively low. To put these findings into perspective, if this were an accurate estimate of the prevalence likely to be experienced by a dive boat taking 25 divers out for two dives per day during 200 days per year (10,000 diver-dives per annum), they could expect divers to run out of air during 18 dives, 77 divers to have reported buoyancy problems, 63 reports of ascending rapidly and 49 dives with a recorded rapid ascent (43 of those in addition to six who would report the rapid ascent), making a total of 201 problems per year, or an average of one event per day. Because these problems are known risk factors for the most common types of diving morbidity and mortality, even such a low prevalence as we report here should be cause for concern aboard dive boats of all sizes.

In conclusion, we recommend dive instructors give greater emphasis during basic diver training to monitoring gas reserves, effective buoyancy control techniques (especially when using drysuits) and the importance of ascending slowly, coupled with practical methods of gauging ascent rate, (such as monitoring the depth-meter rather than looking up to the surface). We especially encourage commercial dive boat crew to consider the workload likely to be experienced when selecting dive sites and to warn divers against overexertion.

References

1 Denoble P, Pollock N, Vaithiyanathan P, Caruso J, Dovenbarger J, Vann R. Scuba injury death rate among DAN members. *Diving and Hyperbaric Medicine*. 2008;38:182-8.
2 Boycott AE, Damant GCC, Haldane JS. The prevention of

compressed air illness. *J Hyg (Lond).* 1908;8:342-443.
3 Neuman TS. Arterial gas embolism and decompression sickness. *News in Physiol Sci.* 2002;17:77-81.
4 Acott CJ. South Australian diving-related deaths 2001-2002. A coroner's inquiry. *SPUMS Journal*. 2004;34:130-6.
5 Edmonds C, Walker D. Scuba diving fatalities in Australia and New Zealand: The human factor. *SPUMS Journal*. 1989;19:94-104.
6 Dovenbarger J, Wachholz C, Bennett PB. Divers Alert Network, DAN Accident Data. *Safe Limits. An international dive symposium*. Cairns, QLD: Division of Workplace Health and Safety; 1994. p. 39-51.
7 Paras. *Scuba diving. A quantitative risk assessment*. Newport, Isle of Wight: Health and Safety Executive; 1997. Report No:140.
8 Vann RD, Denoble P, Dovenbarger J, Freiberger JJ, Pollock NW, et al. *Report on decompression illness, diving fatalities and project dive exploration*. 2004 edition (based on 2002 data). Durham, NC: Divers Alert Network; 2004.
9 Hart AJ, White SA, Conboy PJ, Bodiwala G, Quinton D. Open water scuba diving accidents at Leicester: five years' experience. *J Accid Emerg Med*. 1999;16:198-200.
10 Walker D, Lippmann J. Provisional report on diving-related fatalities in Australian waters 2003. *Diving and Hyperbaric Medicine*. 2009;39(1):4-19.
11 Acott C. Diving incidents - Errors divers make. *Safe Limits: An international dive symposium*. Cairns, QLD: Division of Workplace Health and Safety; 1994. p. 25-38.
12 Cumming B. *NDC Diving incidents report.* South Wirrel, Cheshire: The British Sub-Aqua Club; 2005.
13 Buzzacott P. *Diving injuries amongst Western Australian scuba course graduates* [Masters Degree thesis]. Perth: University of Western Australia; 2006.
14 Edmonds C, Walker D. Scuba diving fatalities in Australia and New Zealand: the environmental factor. *SPUMS Journal*. 1990;20(1):2-4.
15 Edmonds C, Walker D. Scuba diving fatalities in Australia and New Zealand: the equipment factor. *SPUMS Journal.* 1991;21(1):2-5.
16 Denoble PJ, Vann RD, Freiberger JJ, Brubakk A. Pattern analysis of depth-time profiles recorded by dive computers [abstract]. *Undersea Hyperb Med*. 2004;31(3):327.
17 Richardson D, editor. *Go Dive*. Rancho Santa Margarita, CA: International PADI Inc; 1999.

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Peter Buzzacott, BA, MPH, is a doctoral student at the School of Population Health, the University of Western Australia.
Petar J Denoble, MD, DSc, is Senior Research Director, Divers Alert Network (DAN).
Richard Dunford, MSc, is a researcher at Duke University and at DAN.
Richard D Vann, PhD, is Vice-President of Research, DAN.

Address for correspondence:
Peter Buzzacott
School of Population Health,
The University of Western Australia,
35 Stirling Highway, WA 6009, Australia.
Phone: *+61-(0)8-9721-1479*
E-mail: *<pbuzzacott@meddent.uwa.edu.au>*