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Recreational scuba diving equipment problems, morbidity and mortality: an overview of the Diving Incident Monitoring Study and Project Stickybeak

Christopher J Acott

Key words
Diving equipment, scuba, incidents, injuries, morbidity, deaths, survey

Abstract
Recreational scuba diving is an equipment-orientated sport. Equipment problems may be inconvenient but may also cause a diver harm. Data from the Diving Incident Monitoring Study (DIMS) and Project Stickybeak were analysed for reports that involved diving equipment and either morbidity (DIMS) or mortality (Project Stickybeak). There were 426 incidents involving scuba diving in the first 1000 incidents reported to the DIMS, of which 128 (30%) were associated with morbidity. Project Stickybeak recorded 207 recreational scuba diving deaths in Australasia between 1972 and 1996. One hundred and twelve of these reports contained incidents involving equipment, with 43 (38%) of these being associated with the diver's death. Amongst a wide range of equipment problems reported, the most common (48% in the DIMS) were those relating to buoyancy compensation devices, while regulator incidents also featured prominently. Careful pre-dive checks, dive planning and a training emphasis on buoyancy control and weight belt release could have prevented the majority of the equipment problems reviewed and their consequent morbidity.

Introduction

Diving is an equipment-oriented sport, so it is inevitable that some equipment problems will at best be inconvenient and at worst harmful.[1–6] Identification of the problems associated with the use of diving equipment and the development of corrective strategies will help minimise these problems and improve diving safety. The Diving Incident Monitoring Study (DIMS) commenced in 1989 with a pilot study.[7] An analysis of Australasian diving deaths, called Project Stickybeak, was commenced in 1972 by Douglas Walker.[8,9]

The methodology of incident reporting has been discussed in previous articles.[10–14] Incident reporting data are qualitative, not quantitative, and emphasise error and not culpability. Such reporting enables corrective strategies to be developed that may minimise the effects of these errors or problems.

Project Stickybeak data are obtained from fatality/accident reports. Fatality or morbidity data are subject to:

- a simplistic recollection of events due to memory degradation;
- difficulty in obtaining necessary details because of medicolegal restraint and the 'blame model';
- investigator bias due to preconceived theories and prejudices.[11]

Methods

Data on all incidents/accidents associated with morbidity and equipment problems in the first 1000 incidents reported to the DIMS were examined. These data have been reported previously.[4] In addition, data on deaths associated with equipment problems recorded over a 25-year period (1972–1996) in Project Stickybeak were examined.[8,9] The author's opinion concerning the importance of these equipment problems may differ from those recorded by Walker in his publications. For this article, incidents/problems involving the use of an air compressor and surface supply ('hookah' diving) are not included because these are classified under 'hookah' deaths in Project Stickybeak.

Results

There were 426 equipment incidents involving scuba diving in the first 1000 incidents reported to the DIMS. One hundred and twenty eight (30%) of these incidents resulted in harm. Those equipment incidents associated with morbidity are listed in Table 1.

Project Stickybeak recorded 207 recreational scuba diving deaths in Australasia between 1972 and 1996.[8,9] One hundred and twelve of these reports contained incidents involving equipment with 43 (37%) of these being associated with the diver's death (Table 1).

Problems have been reported with all components of the scuba diver's equipment (Table 1). The most common, 48 (37.5%) of the 128 reported incidents causing morbidity, are those relating to buoyancy compensation devices (BCD), while regulator incidents (18, 14%) also feature prominently.

TABLE 1
MORBIDITY AND FATALITY DATA FROM THE DIVING INCIDENT MONITORING STUDY AND PROJECT STICKYBEAK ASSOCIATED WITH EACH PIECE OF EQUIPMENT (BCD = buoyancy compensation device)

EQUIPMENT	DIMS		PROJECT STICKYBEAK	
	Number	Morbidity	Number	Mortality
BCD	154	48	35	14
Regulator	52	18	20	5
Contents gauge	37	10	3	2
Weight belt	33	4	16	9
Alternative air source	31	9	0	0
Mask	28	15	13	3
Tank	22	1	4	1
Fins	21	0	13	4
Computer	11	6	0	0
Wetsuit	10	4	3	1
Depth gauge	9	2	0	0
Dive tables	9	6	0	0
Exit ladder	5	4	0	0
J-valve	2	0	2	2
Snorkel	2	1	1	0
Trophy bag	0	0	1	1
Multiple gas supplies	0	0	1	1
TOTAL	**426**	**128 (30%)**	**112**	**43 (37%)**

The types of injury or morbidity associated with the DIMS equipment incidents are shown in Table 2. Decompression illness (DCI – decompression sickness and cerebral arterial gas embolism) occurred in 65 divers (51%) of the incidents reported. Salt water aspiration and near drowning occurred in 30 (23%) divers.

A wide range of problems have occurred with BCD use in both the DIMS and Project Stickybeak, and are listed together in Table 3. BCD incidents, particularly those associated with the inflation and deflation mechanisms resulting either from mechanical failure or operator error, tend to be associated with severe morbidity such as DCI or near drowning. Difficulties with weight belts are listed in Table 4, and mask problems in Table 5. Regulator, diving suit, gauge and other miscellaneous equipment problems are reported in more detail in accompanying papers.[15–17]

Discussion

The data obtained from both the DIMS and Project Stickybeak reports compliment each other. The errors or equipment problems associated with harm in the DIMS reports are similar to those associated with a fatality in Project Stickybeak. Some researchers consider that an accident or death is often the product of unlikely coincidences, or errors occurring at an inopportune time, when there is no ‘system flexibility’.[18] This view is reinforced by the incidents involving equipment problems in these morbidity and fatality data. Therefore, using data from any incidents to design corrective strategies should decrease both morbidity and mortality.

There is a deliberate lack of ‘numbers’ relating to the reporting of each type of incident in the DIMS data, that is, the number of times a specific incident occurred. This is because incident reporting provides qualitative not quantitative data and is a sampling of what occurs. Some incidents may appear ‘trivial’ and hence go under-reported, while others may be considered ‘important’ and hence are always reported. However, any corrective strategies that are designed from the data must consider all incidents, not just those that are reported frequently.

Nevertheless, errors or problems involving the BCD were by far the most commonly reported in the first 1,000 DIMS incidents and in equipment problems reported in Project Stickybeak. These data are disturbing considering that a BCD is regarded as an essential part of the equipment necessary for safe diving. Choosing the correct size BCD will eliminate any restriction of respiration when inflated or any overlapping of the weight belt that would decrease its accessibility during an emergency. Errors associated with BCD use have been discussed previously.[3,4,6] This serious issue has not been effectively addressed by the dive manufacturing or training industries.

Recreational scuba diving is an equipment-oriented sport. However, there are no regulations or standards that govern

TABLE 2
MORBIDITY RECORDED IN THE DIVING INCIDENT MONITORING STUDY ASSOCIATED WITH EQUIPMENT PROBLEMS
(BCD = buoyancy compensation device)

MORBIDITY	EQUIPMENT ASSOCIATED
Decompression sickness (n = 45)	17 BCD
	6 computer
	6 dive tables
	4 contents gauge
	4 alternative air source
	2 weight belt
	2 mask
	2 depth gauge
	1 wetsuit
	1 regulator
Salt water aspiration (n = 27)	9 regulator
	7 mask
	5 alternative air source
	4 BCD
	1 snorkel
	1 contents gauge
Cerebral arterial gas embolism (n = 22)	12 BCD
	3 regulator
	3 contents gauge
	2 weight belt
	2 mask
Pulmonary barotrauma (n = 18)	10 BCD
	3 regulator
	2 contents gauge
	2 mask
	1 wetsuit
Injured fingers or toes (n = 4)	3 exit ladder
	1 tank
Near drowning (n = 3)	2 BCD
	1 regulator
Ear or sinus barotrauma (n = 2)	2 BCD
Mask squeeze (n = 2)	2 mask
Diver found unconscious (n = 1)	1 regulator hose rupture
Hypothermia (n = 1)	1 wetsuit
Lacerated scalp (n = 1)	1 exit ladder
Coral sting (n = 1)	1 wetsuit
Not specified (n = 1)	1 BCD

TABLE 3
BCD PROBLEMS REPORTED IN THE DIVING INCIDENT MONITORING STUDY AND PROJECT STICKYBEAK
(BCD = buoyancy compensation device)

DIMS

1 BCD leaked
2 Dump valve malfunctioned
3 Fully inflated, BCD restricted the diver's respiration
4 Power inflation mechanism not connected
5 Insufficient air in the diver's tank to inflate BCD
6 Inflation mechanism jammed
7 Diver unable to locate the inflator
8 Inflator hose punctured
9 Separate air inflation cylinder empty
10 Inflation mechanism spontaneously activated
11 Diver did not know how to use the oral inflator
12 Confusion between the deflate and inflate buttons
13 BCD uncomfortable to wear
14 Deflation rate of BCD inadequate

PROJECT STICKYBEAK

1 BCD leaked
2 Dump valve malfunctioned
3 Fully inflated, BCD restricted the diver's respiration
4 Difficulty with oral inflation
5 Incorrect power inflator for the victim's BCD
6 CO_2 cartridges corroded and failed to inflate BCD
7 Foreign body obstructing the oral inflator

recreational diving equipment. It is recommended that some equipment, the breathing regulator for instance, be serviced annually irrespective of use, but there is no requirement for analogue gauges to be recalibrated once purchased. In addition, there is no requirement to supply data on the function of a regulator at various depths, various cylinder pressures, or under increased workloads.

Accompanying papers discuss regulators, diving suits, gauges, and a variety of other items of equipment, including fins, decompression tables, dive computers, depth gauges, snorkels and exit ladders.[15–17] Almost every item of equipment has been associated with mordity, and some of these are highlighted here. Lack of maintenance, failure to check or incorrect use were the main contributory factors.

Whilst uncommon in Australasia, the pillar J-valve may still be used in older European diving equipment to indicate the remaining air supply. The problems with J-valve use would be eliminated by the use of an accurate contents gauge. However, if a diver is using a cylinder with this type of pillar valve, then he/she should be aware of how it is activated and ensure that it is in the upright position before diving.

TABLE 4
WEIGHT BELT PROBLEMS REPORTED IN THE DIVING INCIDENT MONITORING STUDY AND PROJECT STICKYBEAK

DIMS

1. Dislodged during dive (not secured correctly), causing rapid ascent
2. Weight belt dropped during emergency snagged on other equipment (knife, BCD harness)
3. Weight belt buckle not securely fastened
4. Weight belt unreleasable due to the overlapping tongue being twisted around the belt
5. Change in position of the weight belt during the dive prevented emergency jettisoning

PROJECT STICKYBEAK

1. No quick release
2. Quick release jammed
3. Weight belt covered by a large BCD preventing it from being released
4. Weight belt dropped during emergency snagged on other equipment (knife, BCD harness, trophy bag)
5. Weight belt unreleasable due to the overlapping tongue being twisted around the belt

TABLE 5
MASK PROBLEMS REPORTED IN THE DIVING INCIDENT MONITORING STUDY AND PROJECT STICKYBEAK

DIMS

1. Mask squeeze
2. Flooding causing panic
3. Clearing causing panic
4. Mask dislodged causing panic
5. Unable to clear mask (bad technique)

PROJECT STICKYBEAK

1. Flooding causing panic
2. Clearing causing panic
3. Dislodged

The failure of a contents gauge that measures air cylinder pressure has been reported to be the major cause of morbidity and mortality in 'out of air' problems in other studies.[1,5] Currently, there is no requirement for contents gauges to be recalibrated or serviced following purchase. Gauge inaccuracies were reported at every stage of a dive, although the majority were confined to the latter stages when cylinder air pressures were low.[5] Measures that could minimise the effect of these incidents have been discussed.[3–5] Training programmes need to emphasise depth, time, and air consumption calculations. These calculations must be included in pre-dive planning.

Weight belt problems featured in both the morbidity and mortality reports. Problems with weights and weight belts have been reviewed extensively.[1,3,4,7,8] Trainees should be taught the importance of a functioning, accessible (not covered by other equipment), quick-release buckle, the adverse effects of too much tongue overlap, how to slow an uncontrolled ascent, and to 'overlearn' weight belt release in an emergency. In particular, for emergency release of a weight belt, a procedure to avoid accidental entanglement with other pieces of the diver's equipment must be emphasised.

The use of an alternative air source (a 'bail out bottle', or a separate redundant air cylinder and regulator) may enable a diver who has experienced a regulator failure or any other cause of an out of air situation to ascend safely.[5] However, in some incidents these redundant systems had an inadequate supply of air to allow the diver to ascend safely.[4,5] Air consumption calculations (using a 70 kg male) reveal that to ascend to the surface from any depth in the recreational air diving range, including 'safety stops' or required decompression stops, a 560 litre (20 cubic foot) cylinder is required.[4]

Flooding or dislodgment of the mask can cause panic. Not only should mask clearing and equalisation be emphasised during training, but the ability to continue a dive without a mask should it become displaced. This is an essential skill that needs to be mastered by all divers.

Checking that the compressed gas cylinder is securely fastened in a backpack or BCD is part of the pre-dive routine. Regulations stipulate that compressed gas cylinders are inspected annually. Rust in a cylinder will decrease the amount of oxygen available in the stored compressed gas mixture due to oxidisation. In addition, rusty cylinders are an explosion hazard.

Conclusions

A thorough pre-dive check, good pre-dive planning, and an increase in training in buoyancy control and weight belt release could have prevented the majority of the problems reported. A template for a pre-dive check developed from all the incidents reported to the DIMS and Project Stickybeak, whether they caused harm or not, needs to be developed.

References

1 Edmonds C, Walker D. Scuba diving fatalities in Australia and New Zealand. Part 3. The equipment factor. *SPUMS J* 1991; 21: 2-4

2 Bennett PB. Equipment and diving accidents. *Diving Accident Management. 41st Undersea and Hyperbaric Medical Workshop*. Bethesda: UHMS, 1990; 128
3 Acott CJ. Equipment malfunction in 1000 diving incidents. *SPUMS J* 1999; 29: 122-126
4 Acott CJ. 457 equipment incident reports. *SPUMS J* 2001; 31: 182-195
5 Acott CJ. Incident reporting: out of air and diving safety. *Proceedings of the XXth Annual Meeting of the European Underwater and Baromedical Society on Diving and Hyperbaric Medicine*. Cimsit M, Aktas S, Aydin S, editors. Istanbul: Hyperbaric Medicine and Research Centre (HITAM), 1994; 32-41
6 Acott CJ. An evaluation of buoyancy jacket safety in 1000 diving incidents. *SPUMS J* 1996; 26: 89-94
7 Acott CJ, Sutherland A, Williamson JA. Anonymous reporting of diving incidents: a pilot study. *SPUMS J* 1989; 19: 18-21
8 Walker D. *Report on Australian Diving deaths: 1972–1993*. Melbourne: JL Publications, 1998
9 Walker D. *Report on Australian Diving deaths: 1994–1998*. Melbourne: JL Publications, 2002
10 Acott CJ. Scuba diving incident reporting, the first 125 reports. *SPUMS J* 1992; 22: 218-221
11 Runciman WB, Sellen A, Webb RK, Williamson JAW, Currie M, Morgan C, Russell WJ. Errors, incidents and accidents in anaesthesia practice. *Anaesth Intensive Care* 1993; 21: 506-519
12 Flannagan JC. The critical incident technique. *Psychol Bull* 1954; 51: 327-358
13 Webb RK, Currie M, Morgan CA, Williamson JA, Mackay P, Russell WJ, Runciman WB. The Australian Incident Monitoring Study: an analysis of 2000 incident reports. *Anaesth Intensive Care* 1993; 21: 520-528
14 Cooper JB, Newbower RS, Long C, McPeel B. Preventable anaesthesia mishaps: a study of human factors. *Anesthiol* 1978; 49: 399-406
15 Goble S, Acott CJ. Regulator incidents: 52 incidents from the Diving Incident Monitoring Study. *SPUMS J* 2003; 33: 30-34
16 Knight , Acott CJ. Depth gauges, contents gauges and miscellaneous equipment problems reported in the Diving Incident Monitoring Study. *SPUMS J* 2003; 33: 34-37
17 Williams G, Acott CJ. Exposure suits: a review of thermal protection for the recreational diver. *SPUMS J* 2003; 33: 37-40
18 Allnutt MF. Human factors in accidents. *Br J Anaesth* 1987; 59: 856-864

Dr CJ Acott, FANZCA, DipDHM, is the Coordinator of the Diving Incident Monitoring Study (DIMS) and a consultant for the Diver Emergency Service.
He is Director of Diving Medicine, Royal Adelaide Hospital Hyperbaric Medicine Unit, Department of Anaesthesia and Intensive Care,
Royal Adelaide Hospital, North Terrace, Adelaide
South Australia 5000, Australia.
***Phone:** +61-(0)8-8222-5514*
***Fax:** +61-(0)8-8232-4207*
***E-mail:** <cacott@optusnet.com.au>*

Regulator incidents: 52 incidents from the Diving Incident Monitoring Study

Steve Goble and Christopher J Acott

Key words
Diving equipment, scuba, incidents, injuries, morbidity, deaths, survey

Abstract
The functions of the scuba regulator are to reduce the high pressure in the cylinder to the ambient pressure of the diver and to supply sufficient air for the diver to breathe. As such, it is the diver's most important piece of life support equipment. Unfortunately, it is also one of the most neglected. Of the 457 incidents involving equipment reported to the Diving Incident Monitoring Study, 52 (11.4%) involved either the first or second stage regulator. Eighteen (33%) of these incidents resulted in morbidity. Lack of regular servicing, poor or nonexistent pre-dive checks, and lack of post-dive maintenance all contributed to these incidents. Taking time to give all equipment a thorough clean and inspection both pre- and post-dive, as well as adhering to strict dive safety practices, can all minimise the frequency of these incidents.

Introduction

The functions of the scuba regulator are to reduce the high pressure in the cylinder to the ambient pressure of the diver and to supply sufficient air for the diver to breathe. It is the diver's most important piece of life support equipment. Unfortunately, it is also one of the most neglected.

While it is inevitable that a regulator can malfunction at some stage during its working life, there are a number of strategies that can minimise the risk of equipment failure. Good pre- and post-dive maintenance, regular professional servicing, buying well designed equipment, and taking time to learn how your regulator works can all minimise the risk of your regulator malfunctioning.