ORIGINAL PAPERS

EQUIPMENT MALFUNCTION IN 1,000 DIVING INCIDENTS

Chris Acott

Abstract

Among the first 1,000 incidents reported to the Diving Incident Monitoring Study, 105 (10%) were consistent with defined criteria for "pure" equipment failure. Of these incidents 57 (54%) involved a regulator or air supply, 24 (23%) involved a buoyancy jacket power inflator, 14 (13%) involved a depth or timing device and 11 (10%) involved some other diving equipment. Over a quarter of these incidents resulted in harm to the diver. A meticulous pre-dive check, the use of back-up equipment, additions and alterations to equipment design and adherence to strict standard diving safety practice will minimise the effects of all these equipment failures.

Key Words

Equipment, incidents, injury.

Incident reporting

Safety in diving is dependent upon an adequate understanding of the associated risks. Accident and fatality data are used as an index of safety and risk but are retrospective. Accidents are unpredictable,[1] therefore the development of strategies to prevent future accidents from retrospective analyses of accidents is imprecise and difficult.[2] Other limitations associated with accident/fatality data are: often events are reconstructed from a jigsaw of information that lacks substantiation of events by the victim; valuable information may be forgotten during the turmoil of the rescue and resuscitation so that the recorded events may be an oversimplication of what happened;[1] events are often changed to suit the perception of what happened and are seen in the light of "doing the right thing",[1,3] and reports may be either subject to investigator bias and report "what must have happened" and not what did happen, or only legal issues may be addressed.[4]

It is easier to predict and prevent errors, rather than accidents, because errors are methodical, take on predictable forms and can be classified.[1,5] Because an accident is often the product of unlikely coincidences or errors occurring at an inopportune time when there is no "system flexibility",[1] it is reasonable to assume that error prevention will also prevent accidents. It must be noted that most errors occur repeatedly, cause no harm and are recognised and corrected before they progress to an accident.[1]

Incident reporting is a method of identifying, classifying and analysing human error in the context of contributing and associated factors.[6-8] This method is now established in aviation,[9,10] the nuclear power industry and medicine, particularly in anaesthesia.[11,12] It is not a new concept, having been first used in the 1940s to improve military air safety, although the idea had its foundations much earlier, in 19th century Britain.[13] Practitioners of incident monitoring do not attempt to measure the absolute occurrence of any error, to solicit any specific type of error or to match one type of error to morbidity/mortality. Incident monitoring focuses on the process of error, regardless of outcome, and has no interest in culpability or criticism. Monitoring of incidents cannot identify the absolute incidence of error, but will show the relative incidence of errors or identify "clusters" of errors.[1-3,8,11,12] The safety implications of the application of incident monitoring to recreational diving are obviously the identification of the most common and dangerous errors and their contributing factors. This knowledge will help in the development of corrective strategies. Because of its unconstrained nature the application of such a technique will also result in a description of recreational diving practice and demography.

Diving is an equipment orientated sport and control of problems associated with the use of that equipment is an important part of diving safety. While it is inevitable that some equipment will malfunction, it is important to distinguish between true equipment failure or malfunction and problems related to design, misuse or inadequate maintenance so that flaws in equipment can be corrected. True equipment failure is difficult to define because almost every aspect of design, development, manufacture and maintenance involves human interaction. For the purposes of this study, a modified definition to that proposed by Webb[7] will be used:

"Equipment failure occurs when a piece of equipment fails to perform in the manner specified by the manufacturer, providing that it had been maintained and checked prior to use in accordance with the manufacturer's recommendations".

Previous reports of diving equipment malfunction or failure have shown these problems to be at best inconvenient and at worst harmful.[14-16] However, in these reports it is unclear whether there was a "true" equipment malfunction or if the problem arose as a result of equipment misuse or misassembly. Also, the way in which the equipment problem caused or contributed to any consequent accident was not identified. It was consequently decided to identify all the incidents involving "true" equipment failure (as defined by the above criteria) among the first 1,000 incidents reported to the Diving Incident Monitoring

Study (DIMS) and to propose strategies that could either prevent these faults from recurring or minimise their effects.

Method

Using the aviation[9] and anaesthesia[6] models, a diving incident report form was developed in 1988[8] and has since been modified. These forms have been distributed throughout the Australian and New Zealand diving community.

A diving incident is defined as any error or unplanned event that could have or did reduce the safety margin for a diver on a particular dive. An error can be related to anybody associated with the dive and can occur at any stage during the dive. An incident can also include equipment failure.

Divers are encouraged to fill out a DIMS form as soon as they have witnessed or have been involved in an incident. Anonymity is assured by the design of the questionnaire. This allows for accurate reporting without personal identification and legal exposure. Once reported, the data are collected and analysed and any identifying feature, if present, is removed.

The first 1,000 diving incidents reported to DIMS were examined for evidence of equipment malfunction or failure.

Results

There were 105 episodes of equipment failure amongst the first 1,000 incidents reported to DIMS and these are listed in frequency of occurrence in Table 1. Twenty seven of these were associated with morbidity and are listed in Table 2.

Fifty four percent of the reported incidents involved the diver's regulator and air supply, 23% the diver's buoyancy jacket, 13% dive computers and depth gauges and 10% miscellaneous diving equipment.

Discussion

This report of 10% of all diving incidents being due to true equipment failure is similar to previously published reports of accidents and incidents involving interaction between humans and machines in aviation, medicine and in industry. These studies show that between 8 and 10% of incidents arise from true equipment failure.[3,7,10] However, it must be noted that in the context of diving incidents, most equipment problems reported to DIMS were associated with equipment misuse, lack of understanding of how the equipment functioned, or to poor equipment design,

TABLE 1

105 EQUIPMENT FAILURES CLASSIFIED AND RANKED ACCORDING TO FREQUENCY

Type of Equipment	Incidents	Morbidity
Air supply	**58**	
Contents gauge	33	9
Regulator first stage	12	3
LP hose rupture	8	
Alternative air source	4	
Air cylinder	1	
Buoyancy jacket	**24**	
Inflator failure	14	2
Spontaneously inflated	10	5
Depth & timing devices	**14**	
Computer	11	6
Depth gauge	3	2
Miscellaneous	**9**	
Fins	5	
Surface signalling device	3	
Torch	1	
TOTAL	**105**	**27**

TABLE 2

MORBIDITY ASSOCIATED WITH EQUIPMENT FAILURE
(LISTED IN ORDER OF FREQUENCY)

Morbidity	Incidents	Cause
DCS	14	6 (C) 4 (CG) 2 (D) 2 (I)
Pulmonary Barotrauma	5	2 (F) 2 (CG) 1 (I)
CAGE	2	2 (CG)
Salt water aspiration	1	1 (CG)
PBT with CAGE	1	1 (I)
Near drowning	1	1 (F)
Ear barotrauma	1	1 (I)
Not specified	2	2 (I)
Total	**27**	**27**

Causes

(C) = Computer failure (6 cases).
(CG) = Contents gauge failure (9 cases).
(D) = Depth gauge failure (2 cases).
(I) = Inflator failure (spontaneous inflation 5 cases, failure 2 cases).
(F) = First stage failure (3 cases).

maintenance and servicing. These incidents will be the subject of a future report.

DIMS has identified failure of a contents gauge (that measures air cylinder pressure) as a major cause of morbidity in this study . It has been reported to be the major cause of "out of air" problems and morbidity in earlier studies.[17-19] Gauge inaccuracy was reported at every stage of a dive, although the majority were confined to the latter stages when cylinder air pressures were low. Currently, contents gauges are not required to be recalibrated or serviced following purchase.

Measures that could minimise the effect of these incidents include: a requirement for the recalibration of contents gauges with an annual regulator service; a thorough pre-dive contents gauge check, as described previously;[17] dive planning that includes depth, time and air consumption calculations; and an audible alarm (set at 50 bar) in the tank pillar valve and the contents gauge.

Regulator first stage failure and low pressure hose rupture did not necessarily occur when the air supply was at maximum pressure. In the reported incidents, 6 of the regulator first stage failures and 6 of the low pressure hose ruptures occurred at depth, including 2 new hoses which were not from an established manufacturer. Measures that should reduce the occurrence and minimise the effects of incidents include a visual hose inspection before every dive and the consequent replacement of all doubtful hoses.

The use of an alternative air source, a separate second stage, may enable a diver who has experienced a regulator failure to ascend safely, provided the diver's buddy is close and aware of the diver's predicament. Sharing a second stage is not recommended because published data show that such "buddy breathing" ascents are associated with an unacceptable level of risk.[19] However, in 2 of these incidents, the alternative air source (a power inflator and demand valve combination) developed a leak during the dive (a pre-dive check did not and would not have detected this fault), requiring disconnection to preserve the diver's air supply. Other suggestions to minimise the effect of the sudden loss of an air supply include the addition of a small spare "pony" air cylinder. However, the other two alternative air source incidents involved the failure of the filling mechanism for such pony bottles and the divers concerned conducted the dive without an alternative air source. A diver's response to any emergency is determined, in part, by training. Refresher training programs are available from most training agencies but are not as well patronised as they should be. These enable divers to relearn and practice emergency procedures, particularly, for an out of air problem.

In Australia the required annual inspection and testing of scuba cylinders is an important safety measure.[20] Although cylinder problems are rare, an undetected tank fracture could have explosive and fatal consequences.

The power inflator mechanism of a buoyancy jacket failed to operate in 14 incidents. A meticulous pre-dive check of the inflator would have detected this fault in almost all cases. During 10 separate dive incidents the inflator spontaneously inflated the buoyancy jacket. Consequent rapid changes in buoyancy are dangerous and it is not surprising that 7 of these incidents resulted in morbidity. To minimise the occurrence of these incidents, all jackets should be equipped with an accessible emergency dump valve that is designed to be able to exhaust air at a rate at least equal to that of maximum inflation. Unfortunately not all compensators provide this facility. In addition to this emergency dump valve a cut off mechanism should be added to the power inflator to prevent the rapid depletion of the diver's air supply.

Six of the 11 incidents involving dive computers resulted in harm. To prevent sudden power failures, all computers should be equipped with either a low battery alarm or a mechanism by which the diver can test battery power. None of the divers who reported computer failures to DIMS had access to a set of dive tables. In this context, it is clear that computers should be used to assist dive planning and not as the sole method of dive management. In addition, all divers using computers should dive with an additional timing device and depth gauge.

All of the incidents involving inaccurate depth gauges caused harm. Even when a depth gauge is first purchased, the accuracy of the gauge is not known. Once purchased, there is recommendation for regular recalibration. A sensible safety measure is an annual recalibration. Divers also need to be taught to compare their contents gauge readings with those of their diving companion before, during and after a dive to assess the accuracy of both their calculations and contents gauge. Training programs need to emphasise depth, time and air consumption calculations.

The loss of a fin in an emergency situation may be fatal. In an analysis of diving fatalities, one study reported a 10% incidence of a missing fin or fins.[14] A pre-dive check must include the fin straps.

"Safety sausages", an elongated sausage shaped coloured plastic tube which is extended by filling with air, are usually visible and easily maintained in an upright position in calm conditions, but from reports to DIMS they often fail to maintain their upright position in adverse conditions and are then invisible. These devices need to be made from sturdy material and tested in all conditions before being sold.

Limited visibility diving requires the use of a primary and secondary diving torch to provide continuous light. The water resistance of any diving torch needs to be tested before sale.

Conclusions

One hundred and five (10.5%) of the first 1,000 incidents reported to DIMS conform to a definition of pure equipment failure. Of these 105 incidents, 27 (26%) resulted in harm. Overall, these data are consistent with other papers in that "true" equipment failure accounts for between 8 and 10% of incidents and accidents in systems with interaction between equipment and humans.[3,7,10]

Sixty three (60%) of these reported incidents could be prevented by the combination of a thorough pre-dive check (as defined here) and an annual equipment recalibration.

Another 55 (52%) incidents could have been avoided if either equipment design was altered (the addition of a low battery alarm in dive computers, an audible low pressure alarm in contents gauges and tank pillar valves, a larger more accessible emergency dump valve in all buoyancy jackets and a cut off mechanism to the power inflator) or if there was a change of manufacturing material and testing procedure. It is reasonable to argue that all battery powered equipment should have either a low battery alarm or a monitor that indicates battery status.

Adherence to established diving safety procedures could have reduced the effect of 53 (51%) incidents.[21,22]

Problems associated with regulator first stages (including hoses) do not necessarily occur when the air supply is at maximum pressure. An annual scuba cylinder inspection and test as prescribed in AS3842.2 -1999 is essential.

The effect of another 48 (46%) incidents could have been minimised by the use of back-up equipment such as a second contents gauge, dive timer, depth gauge and torch. If a piece of equipment is considered essential, it is reasonable that at least one level of redundancy (e.g. duplicate equipment) is needed. This attitude is accepted by the Cave Diving Association of Australia.

The strategies proposed to reduce the occurrence and minimise the effects of these equipment failures in diving are summarised in Table 3.

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TABLE 3

EQUIPMENT FAILURES AND STRATEGIES TO MINIMISE OUTCOMES

Equipment	Strategy to be used	Corrective strategies
Contents gauge	1, 2, 3, 4, 9, 11	1 = Recalibration of equipment
Regulator first stage	2, 4, (9?)	2 = Addition to established pre-dive protocol
Buoyancy Jacket		3 = Low pressure alarm
Inflator failure	2, 10	4 = Good buddy diving
Spontaneous inflation	5, 10	5 = Equipment design additions
Fins	2	6 = Change of manufacturing materials
Torch	7, 9	7 = Added testing
Surface signalling device	6, 7	8 = Battery status alarm
Alternative air source	2, 4, 5, 7, 10	9 = Use of back up equipment
Depth gauge	1, 9	10 = Additional servicing
Dive computer	8, 9	11 = Good dive planning
Tank	12	12 = Annual servicing

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TARAVANA REVISITED
DECOMPRESSION ILLNESS AFTER BREATH-HOLD DIVING

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Key Words

Breathhold diving, decompression illness.

Introduction

Decompression Illness (DCI) following breath-hold (BH) diving is extremely rare. In the past there were numerous BH divers around the world, such as Ama and katsugi divers of Japan, hae-nyo divers of Korea and sponge divers of Greece and Turkey, but now this mode of diving is much less common. These divers do not normally suffer from DCI.

Notwithstanding the rarity of DCI from BH diving, it does occur following extremes of BH diving. In 1958 E R Cross reported a condition known as "Taravana" among pearl divers of the Tuamotu Archipelago near Tahiti.[1] These divers did repetitive BH dives and they suffered from what appeared to be symptoms of DCI. Seven years later Paulev, a naval medical officer, described his personal experience of DCI from BH diving.[2]

Due to the rarity of this condition, it is likely that most medical practitioners are unaware of its existence. This paper reviews the condition and reports two Australian cases of DCI from BH diving.

Taravana

E R Cross described a diving syndrome, called Taravana, in Tuamotu Islander divers working in the Takatopo Lagoon.[1] Taravana is a Paumotan name meaning to fall crazily (tara = to fall; vana = crazily). The report listed 35 male divers. Twelve of them suffered from vertigo and one died. The ages ranged from 19 to 62, and the greatest depth dived was 25 "brasses". A brass is the distance one can reach with outstretched arms and