ORIGINAL PAPERS

457 EQUIPMENT INCIDENT REPORTS

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Key Words

Accidents, equipment, incidents, morbidity, recreational diving, safety.

Abstract

Diving is an equipment orientated sport and identification and elimination of problems associated with the use of that equipment is an important part of diving safety.

There were 457 incidents involving equipment in the first 1,000 incidents reported to the Diving Incident Monitoring Study (DIMS). One hundred and thirty six of these incidents resulted in morbidity, therefore, 30% of the equipment problems caused harm. They constituted 28% of the total morbidity reported.

A meticulous pre-dive check, the use of back-up equipment, additions and alterations to equipment design and manufacturing materials, regular servicing, post-dive maintenance, recalibration of all gauges and adherence to strict standard diving safety practice will minimise equipment problems.

Introduction

Safety in diving is dependent upon an adequate understanding of the associated risks. Diving is an equipment-orientated sport and the identification and elimination of problems associated with equipment use is an important part of diving safety. While it is inevitable that some equipment will malfunction, other problems will be due to; a lack of understanding of equipment function, poor equipment design, poor servicing, equipment misuse or inadequate post dive maintenance. Previous reports of diving equipment malfunction/failure have shown that these are at best inconvenient and at worst lethal.[1-4]

An accident is often the product of unlikely coincidences or errors occurring at an inopportune time when there is no "system flexibility".[5] It is reasonable to assume that error prevention will also prevent accidents because it is easier to predict and prevent errors rather than accidents.[6,7] It must be noted, however, that most errors occur repeatedly, cause no harm and are recognised and corrected before they progress to an accident.[5]

Incident reporting is the study of error and unintentional events. It is a method of identifying and analysing error in the context of contributing and associated factors.[7,8] 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.[9] It is now an established part of safety in aviation, the nuclear power industry and anaesthesia.[10-15]

Incident monitoring focuses on the process of error, regardless of outcome, and has no interest in culpability or criticism. Monitoring of incidents can not identify the absolute incidence of error, but will show the relative incidence of errors or identify "clusters" of errors.[6-8,12,13] In Australia the Anaesthetic Incident Monitoring Study (AIMS) was introduced in the 1980s and provided evidence of unsuspected weaknesses in past anaesthetic training which have since been corrected.

The safety implications of the application of incident monitoring to recreational diving include the identification of the most common and dangerous errors and their contributing factors. Identification of such errors may suggest corrective strategies which may lead to the reduction or elimination of their effects.[16-19]

Method

A diving incident form was designed in 1988 and has since been modified.[16] These forms were distributed throughout Australia and New Zealand. A diving incident is defined as any error or unplanned event that could or indeed 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 one of these forms as soon as they have witnessed or have been involved in an incident. Anonymity is assured by the design of the questionnaire.

Data on all incidents associated with equipment problems (including poor design, poor servicing, a lack of servicing or recalibration, ignorance of the equipment's function and equipment misuse) in the first 1000 incidents reported to the Diving Incident Monitoring Study (DIMS) were examined.

For the purpose of this study equipment misuse occurred when a piece of equipment was used in a manner for which it was not designed or specified. Included in the reports examined were incidents in which true equipment malfunction (defined as: "when a piece of equipment fails to perform in the manner specified by the manufacturer, providing it had been maintained and checked prior to use in accordance with the manufacturer's recommendations.") occurred. These true equipment malfunction incidents have been discussed previously.[4]

Results

There were 457 incidents involving equipment in the first 1,000 incidents reported to the Diving Incident Monitoring Study (DIMS). One hundred and thirty six of these incidents involved morbidity, therefore 30% of the equipment problems involved harm. These harmful equipment problems constituted 28% of the total morbidity reported. Tables 1 and 2 list the number of reported incidents and morbidity associated with each reported piece of equipment. Previous published data concerning "true equipment malfunction" (TEM) is also included in Table 1

TABLE 1

MORBIDITY ASSOCIATED WITH EACH PIECE OF EQUIPMENT

Equipment	Number of divers	Morbidity (%of cases)		TEM (morbidity)	
BCD	154	48	(31%)	24	(7)
Regulator	52	18	(33%)	20	(3)
Contents gauge	37	10	(27%)	33	(9)
Weight belt	33	4	(12%)		
Alternative air source	31	9	(29%)	4	(0)
Mask	28	15	(54%)		
Tank	22	1	(4%)	1	(0)
Fins	21	0	(0%)	5	(0)
Computer	11	6	(54%)	11	(6)
Compressor	10	5	(50%)		
Wet suit	10	4	(40%)		
Depth gauge	9	2	(22%)	3	(2)
Dive tables	9	6	(67%)		
Surface signaling device	8	0	(0%)	3	(0)
Exit ladder	5	4	(80%)		
Light source	4	0	(0%)	1	(0)
Compressor air hose kinked	3	2	(67%)		
J valve	2	0	(0%)		
Snorkel	2	1	(50%)		
Scooter	1	0	(0%)		
Surface line	1	0	(0%)		
Compressor air hose rupture	1	1	(100%)		
Knife	1	0	(0%)		
Video camera	1	0	(0%)		
Shot line	1	0	(0%)		
Totals	**457**	**136**		**105**	**27**

Note TEM = True Equipment Malfunction.

TABLE 2

MORBIDITY ASSOCIATED EQUIPMENT PROBLEMS

Decompression sickness 48 cases	17 BCD problems 6 computer problems 6 dive tables problems 4 contents gauge problems 4 alternative air source problems 2 weight belt problems 2 mask problems 2 depth gauge problems 2 compressor problems 1 compressor air hose rupture 1 wet suit problem 1 regulator problem
Salt water aspiration 27 cases	9 regulator problems 7 mask problems 5 alternative air source problems 4 BCD problems 1 snorkel problem 1 contents gauge problem
Cerebral arterial gas embolism 24 cases	12 BCD problems 3 regulator problems 3 contents gauge problems 2 weight belt problems 2 mask problems 1 compressor problem 1 compressor air hose kink
Pulmonary barotrauma 18 cases	10 BCD problems 3 regulator problems 2 contents gauge problems 2 mask problems 1 wet suit problem
Near drowning 3 cases	2 BCD problems 1 regulator problem
Ear/sinus barotrauma	2 BCD problems
Mask squeeze	2 mask problems
Contaminated air	2 compressor problems
Crushed finger	2 exit ladder problems
Diver unconscious on bottom (hypoxic)	1 compressor air hose kink 1 regulator hose rupture
Not specified	1 BCD problem
Fractured toe	1 tank problem
Lacerated finger	1 exit ladder problem
Hypothermia	1 wet suit problem
Lacerated scalp	1 exit ladder problem
Coral sting	1 wet suit problem

for comparison. These TEM problems accounted for 105 (10.5%) of the equipment problems reported to DIMS. Of these, 27 (25%) resulted in harm to the diver.[4]

In addition to the 154 Buoyancy Control Device (BCD) incidents studied in this report (Table 3) there were 11 BCD incidents which have not been included in this analysis of equipment problems because they were considered to be related to poor diving technique. These incidents were caused by divers frequently using their BCD power inflator to maintain their buoyancy. This diving technique led to nine out-of-air and two low-air problems. Four of these nine incidents resulted in morbidity.

Discussion

There are no regulations or standards that govern recreational diving equipment. Snorkels are sold without data on their dead space or resistance to breathing. Depth and contents gauges are sold without calibration data although they are assumed to be accurate at the time of purchase. Torches are also sold as pressure-resistant and waterproof without any data to validate these statements. Regulators are arbitrarily recommended to be serviced annually irrespective of use. There are also limited data available concerning individual regulator function at various depths and under increased workload. It is also often assumed by divers that a BCD will float an unconscious diver safely on the surface. Unfortunately this is not always true of modern BCDs. The lack of standards has also allowed ergonomically poorly designed equipment to be available and sold; for example many BCDs have inflate and deflate buttons co-located on the BCD inflator hose, these have been confused during an emergency leading to further problems.

Incident reporting data are qualitative and not quantitative although data obtained are often used in a quantitative manner. Frequently reported errors may represent what is perceived as being important by the reporter, however the data obtained may show the relative incidence or clusters of errors associated with the use of a particular piece of equipment. This study shows that equipment problems are not uncommon in recreational diving and that they are associated with a high incidence of morbidity. They accounted for 46% of the incidents reported and 28% of all the incidents that involved morbidity.

One hundred and five (10.5%) of the first 1,000 incidents conform to a definition of true equipment malfunction.[4] TEM occurs when a piece of equipment fails to perform in the manner specified by the manufacturer, although it had been maintained and checked prior to use in accordance with the manufacturer's recommendations. The DIMS TEM data (23% of the total and 20% of the morbidity) are consistent with published data where TEM accounts for 8 to 10% of incidents and accidents in systems requiring interaction between equipment and human beings.[10,12,20]

Errors or problems involving BCDs, shown in Table 3 were the most commonly reported incidents in the first 1,000 collected. Data concerning these incidents has been previously reviewed.[21] Nearly a third of these incidents were associated with morbidity. These data are disturbing considering that a BCD is regarded as an essential part of equipment necessary for safe diving. However, all of these incidents could have been prevented by use of one or more of the corrective strategies on page 193-195.

TABLE 3

154 BUOYANCY CONTROL DEVICE (BCD) INCIDENTS

Problems (14 different types)

1 The inflation mechanism failed:
   a the power inflation mechanism was not connected;
   b there was not enough air in the diver's tank to inflate the BCD;
   c the inflation mechanism jammed;
   d the diver was not able to locate the inflator;
   e the inflator hose was punctured;
   f a separate air cylinder used to inflate the BCD was empty;
   g the separate air cylinder used to inflate the BCD was turned off in an emergency while trying to activate the inflate mechanism.
2 The inflation mechanism spontaneously activated.
3 Diver did not know how to use the oral inflator.
4 There was confusion between the deflate and inflate buttons.
5 The inflation mechanism was not connected.
6 The BCD leaked.
7 The diver did not know how to deflate the BCD.
8 The dump valve malfunctioned.
9 The BCD was uncomfortable to wear.
10 When fully inflated the BCD restricted the diver's respiration.
11 The BCD was too small and provided inadequate buoyancy.
12 The deflation rate of the BCD was inadequate.
13 Inflation rate was slow at depth.
14 BCD too large.

Misuse

a Full inflation of the BCD was used to retrieve the anchor at the end of the dive.
b Full inflation of the BCD was used to raise a heavy object.

Major contributing factors

a Lack of knowledge of the functions of a BCD
b Failure to check.
c Poor design
d Lack of diver maintenance

1 the purchase or hiring of a BCD should be accompanied by an education program (verbal and video) which stresses the function of each part of the BCD ;
2 a change in design so that inflation and deflation buttons are separated and cannot be confused.
3 a change in design so that the hose deflation button can be used while a octopus integral with the power inflator is being used by a buddy.
4 a meticulous pre-dive BCD check should always be performed;
5 all introductory recreational diver training programs should put greater emphasis on the importance of buoyancy control;
6 a BCD should be washed with fresh water after every dive;
7 a BCD should perhaps be serviced annually; and
8 choosing the correct size BCD.

In addition to these corrective strategies data concerning the function of a regulator at depth or when the air supply is low should be made available at the time of purchase. This may eliminate ignorance of the time taken to inflate a BCD at depth due to a poorly functioning first stage or when the air cylinder contents are low.

Choosing a correct size BCD is important. This will eliminate problems of inadequate buoyancy, restriction of respiration while partially inflated, becoming dislodged during diving and covering the weight belt which reduces access to the weight belt during an emergency.

Trainees, in particular, should be taught to achieve buoyancy control without the use of a BCD, how to slow an uncontrolled ascent and to overlearn the response of weight belt release in an emergency.

Regulator problems are shown inTable 4. First stage failure and low-pressure hose rupture did not necessarily occur when the air supply was at maximum pressure. In the reported incidents regulator first stage failures and low pressure hose ruptures occurred at depth. Diaphragm first stage regulators are more likely to fail than the piston type because they have an upstream valve that can fail to operate so shutting off the diver's air supply. Measures that should reduce the occurrence and minimise the effects of these incidents include the use of an independent redundant air source such as a pony bottle, a visual hose inspection before every dive and the consequent replacement of all doubtful hoses.

Poor servicing of regulators was highlighted in the reported incidents. Free flowing second stages frequently followed the annual service. There are no regulations governing service standards. Divers should test their recently serviced equipment before use and return it to the service person if the service was found to be inadequate.

TABLE 4

52 REGULATOR INCIDENTS

Problems (11 different types)

1 Free flowing second stage.
2 First stage failure.
3 High-pressure hose leaking or rupture.
4 Foreign body in second stage.
5 Second stage allowed the inhalation of water.
6 Mouthpiece worn and fell apart.
7 Increased resistance to breathing at depth (not associated with buddy breathing).
8 Second stage dislodgment from the diver's mouth during the dive.
9 Swivel connector between high-pressure hose and mouthpiece ruptured.
10 First stage connected incorrectly to the tank's pillar valve.
11 A moisturising filter between the high pressure hose and second stage malfunction.

Major contributing factors

a Poor servicing.
b Lack of servicing.
a Lack of diver maintenance.
b Failure to check.

Visual inspection of the regulator mouthpiece (and replacement if required) before each dive would eliminate problems associated with a worn or torn mouthpiece. Divers should be encouraged to use only a mouthpiece which is comfortable to wear and well fitting. This will reduce jaw fatigue and accidental displacement during a dive. Recovery of a displaced regulator is assisted by having a line from the second stage clipped to the BCD.

Some unbalanced first stage regulators perform poorly at depth. Divers may also not realise that when two are breathing from one first stage regulator (either balanced or unbalanced) in a shared air situation, even when the air cylinder contents are not necessarily low, the regulator may malfunction. It is important, therefore, that regulator performance data for each depth and under the situations described should be available.

The addition of unnecessary extras (for example a humidifier) to the low pressure regulator hose only increases the chances of malfunction.

Table 5 shows contents gauge incidents. 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.[19] However, in some incidents redundant systems were not checked as

TABLE 5

37 CONTENTS GAUGE INCIDENTS

Problems (5 different types)

1 Inaccurate gauge.
2 Hose leak.
3 Unable to read the gauge because of poor visibility or red colour numerals.
4 Misreading the gauge because the diver did not understand the units used.
5 Diver did not understand what a fluctuating analogue needle indicated during inspiration.

Major contributing factors

a Failure to check.
b Lack recalibration /servicing.
c Lack of understanding.

TABLE 6

31 ALTERNATIVE AIR SOURCE INCIDENTS

Problems (2 types)

1 Redundant air source or pony bottle.
 a not turned on at beginning of dive.
 b filling mechanism failure.
 c not in an accessible position.
 d depleted during use.
 e inadequate contents.
 f used at beginning of dive incorrectly.
 g empty, not checked prior to diving.

2 Octopus 2nd stage regulator.
 a not accessible in emergency due to poor positioning.
 b free flowing.
 c not working.
 d low pressure hose rupture.
 e depleted air supply quickly when used in emergency.
 f difficulty in breathing from it and main regulator at depth during emergency air sharing,
 g difficulty in breathing from it and main regulator during emergency air sharing,
 h hose and 2nd stage became snagged,
 i not purged during emergency use causing salt water inhalation and panic,
 j low pressure hose too short to be used in an emergency by another diver,
 k placed incorrectly in diver's mouth during emergency.

frequently as the diver's major air supply. In these incidents the additional air supply was noted to be either:

1 turned off, or
2 leaked, or
3 empty at the time when needed; or
4 had an inadequate supply of air to allow the diver to ascend safely.

Table 6 shows alternative air supply incidents. Smaller emergency air bottles, such as Spare Air, which require a filling mechanism to enable them to be filled from the major air supply, were available but not used in some incidents because the filling mechanism was unavailable or had failed to work. These smaller bottles also contain only a limited amount of air and frequently became depleted during emergency use. Air consumption calculations using, the standard 70 kg male, reveal that to ascend to the surface from a depth of 20 m at 10 m/minute, assuming that the emergency has doubled the diver's minute volume from a quiet 20 l/minute to 40 l/minute, would require a surface volume of 160 litres. The larger Spare Air (3 cu ft) contains 84 litres when converted to surface pressure so is obviously inadequate. It would require a pony bottle of 6 cu ft capacity (168 l at surface pressure) to provide enough air for this ascent, provided it was at full pressure when first used. A safety stop for 3 minutes at 5 m would require another 235 litres of surface air, if the diver's minute volume dropped to 30 l/minute. The total needed to reach the surface now becomes 495 l, which rounds off to 500 l. A 2.5 kg (or l) water volume (20 cu ft) cylinder, holding 560 litres, is required.

The addition of another 2nd stage, octopus regulator, to the first stage regulator is considered part of safe diving practice.[22,23] This octopus, however, needs to be:

1 positioned so that any diver wishing to breathe from it has easy access;
2 frequently serviced;
3 fully functional;
4 have minimal resistance; and
5 easily purged.

Some divers have the 1st and 2nd stages of their regulators serviced but often do not service the octopus 2nd stage because it is used infrequently. It should be serviced at the same time.

The combination of a 2nd stage regulator and a low-pressure BCD inflator has no merit. These combinations are extremely difficult to use during an emergency ascent and have resulted in confusion while a diver is trying to breathe from the mouthpiece and deflate the BCD at the same time. These combinations are also not frequently serviced.

The failure of a contents gauge, which measures air cylinder pressure, has been reported to be the major cause of out-of-air problems and morbidity in other published studies.[1,19] Currently, contents gauges are not required to be recalibrated or serviced after purchase. 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. Measures that could minimise the effect of these incidents include:

1 an audible alarm (set at 50 bar) in the tank pillar valve and the contents gauge;
2 a thorough pre-dive contents gauge check using a protocol has been developed from the first 125 incidents,[17,19]
3 recalibration of contents gauges with the annual regulator service;
4 dive planning that includes depth, time and air consumption calculations; and
5 divers should be taught to compare their contents gauge readings with those of their diving companion before and during a dive to assess remaining air and gauge accuracy.

Training programs need to emphasise depth, time and air consumption calculations. These calculations must be included in pre-dive planning. This will help to prevent out-of-air situations associated with the use of smaller tanks. Haste, inexperience and inattention cause divers to not realise that reducing the size of the air cylinder will mean that:

1 less air is available;
2 adjustments to buoyancy will have to be made/ calculated;
3 there will be a decreased length of a dive;
4 there will be a decreased amount of air available should an out-of-air situation develop in another diver and air has to be shared; and
5 less air will be available when the audible alarm is activated.

Problems with weights and weight belts, shown in Table 7, have been reviewed extensively.[1,3,24] In addition to these problems (being snagged on other pieces of equipment, being unreleasable, and not being ditched in an emergency), incident reporting has highlighted other areas of concern:

1 weights dropping from the weight belt when being handled when leaving the water; and
2 weights dropping from a BCD pocket after placed there in a hurried attempt to adjust buoyancy.

The importance of too much tongue overlap causing problems (being wrapped around the belt to prevent rapid release, being snagged by rocks causing accidental dislodgment and the inevitable uncontrolled rapid ascent) also featured in the incidents reported and need to be emphasised during training. Trainees should be taught:

1 how to control a rapid ascent;
2 how to secure a weight belt correctly;
3 that a weight belt should not be overlapped by any other piece of equipment which will prevent its rapid release;
4 how to handle the weight belt at exit; and
5 how to jettison it correctly in an emergency by holding it out from the body so when it falls it is clear of all other equipment.

TABLE 7

33 WEIGHT BELT INCIDENTS

Problems (11 different types)

1 Dislodged during dive (not secured correctly) causing a rapid ascent.
2 Being dropped at the exit.
3 Weights dropping from belt at exit.
4 Tongue overlap becoming snagged and causing weight belt dislodgment.
5 Forgot weight belt.
6 Weight belt dropped during emergency but became snagged on other equipment (knife; BCD harness).
7 Weight belt covered by an overlapping (large) BCD preventing accessibility during an emergency.
8 Weights placed in BCD pocket fell out.
9 Weight belt buckle not securely fastened.
10 Weight belt was unreleasable due to the overlapping tongue being twisted around the rest of the belt.
11 A change in position of the weight belt during the dive prevented emergency jettisoning.

Major contributing factors

a Failure to check.
b Inattention.
c Haste.
d Insufficient training.

Over 50% of incidents involving mask problems caused morbidity (Table 8). Flooding or dislodgment caused panic in many incidents. Five out of the 6 incidents involving mask flooding and panic resulted in diver harm; 2 of the 3 reported incidents involving mask clearing and panic caused harm. Six of the 10 incidents in which the diver's mask was dislodged resulted in harm, although only 1 of these incidents was associated with panic. Mask problems have been reported as a contributing factor in 5% of recreational deaths.[1] Not only should mask clearing be emphasised during training but also the ability to continue a dive without a mask, should it become displaced, is an essential skill that needs to be mastered by ALL divers.

Table 9 shows air cylinder incidents. An annual inspection of air cylinders for faults is an important safety measure. An undetected cylinder fracture could have explosive and fatal consequences. Checking that the air cylinder is securely fastened in a backpack or BCD is part of a pre-dive check. From the incidents reported this is not commonly performed. Incorrectly connecting the first stage to the pillar valve is an indication of inexperience and anxiety and should alert more experienced divers, including the dive leader, to monitor that diver very carefully.

In the incidents involving surface supply (Table 10)

TABLE 8

28 MASK INCIDENTS

Problems (10 different types)

1. Mask squeeze.
2. Flooding causing panic.
3. Flooding not causing panic.
4. Clearing causing panic.
5. Mask strap broke.
6. Mask dislodged causing panic.
7. Mask dislodged without causing panic.
8. Unable to clear mask because of bad technique.
9. Mask leaking.
10. Uncomfortable to wear.

Major contributing factors

a Inexperience.
b Inattention.
c Failure to check.
d Anxiety.

TABLE 9

22 CYLINDER INCIDENTS

Problems (12 different types)

1. Fracture detected in new cylinder.
2. Cylinder not secured properly in backpack or BCD.
3. Cylinder slipping out of BCD.
4. Pillar valve leak.
5. Buoyancy problem because of a change from steel to aluminium cylinder.
6. Buoyancy problem because of aluminium cylinder.
7. O ring rupture.
8. Covering tape left over pillar valve.
9. Tank straps loose, BCD dislodged.
10. Change to smaller cylinder size caused a quicker depletion of air supply leading to an out-of-air situation.
11. Air supply turned off while diver still climbing exit ladder.
12. Incorrect attachment of the regulator to the pillar valve.

Major contributing factors

a Lack servicing/inspection.
b Failure to check.
c Inexperience.
d Anxiety.
e Inattention.
f Haste.
g Poor judgement/decision.

from an air compressor (hookah diving) the compressor was left unattended in many. This resulted in it running out of fuel causing an out-of-air situation. In all of these incidents the divers lacked a bail-out bottle. These incidents are examples of stupidity and no corrective strategies will prevent them. Even if the compressor has an attendant a checked bail-out bottle is essential because air hoses can become snagged, rupture or kink.

Air compressors need regular maintenance. In one incident reported poor compressor maintenance could have resulted in multiple deaths. Poor filtering (due to a lack of maintenance) allowed silica dust to enter the air cylinders during filling. This silica obstructed the air cylinder's pillar valve during use. All the air cylinders filled from this compressor were noted to have silica in them. In addition, none of the air cylinders had been pressure tested or visually inspected before this incident. Regulations governing compressor maintenance are worthless unless a regulatory body (if it exists) performs spot checks. Checking that a hired air cylinder has been recently tested would give a good indication of the shop's equipment maintenance.

TABLE 10

10 COMPRESSOR INCIDENTS

Problems (5 types)

1. Ran out of petrol.
2. No attendant.
3. Contaminated air supply to scuba tanks.
4. Diver using surface supply commenced the dive without turning the compressor on.
5. Compressor air hose kinked or ruptured.

Misuse

a No attendant.

Major contributing factors

a Lack of maintenance.
b Failure to check.

The loss of a fin in an emergency situation may be fatal. In an analysis of diving fatalities, one study reported a 13% incidence of a missing fin or fins. The loss of a fin was thought to be associated with active leg movement during panic or while swimming against a strong current or using a fin too large for the diver's foot.[1] These problems were also highlighted in the incidents received, however, in several incidents breakage of a fin strap occurred which was not associated with strenuous exercise or panic (Table 11). A pre-dive check must include a check of the integrity and tightness of the fin straps.

It is not surprising that some of the incidents involving dive computers (Table 12) resulted in morbidity. Standardisation of the layout of the face, and of the units used, would prevent confusion in reading the displayed data.

To prevent sudden power failures, all computers

TABLE 11

21 FIN INCIDENTS

Problems (3 types)

1 Lost during dive.
  a incorrect for boot size, too large.
  b loose strap.
  c strap broke.
2 Forgot to put fins on before dive.
3 Fins forgotten.

Misuse

a Incorrect size of fin for boot size.

Major contributing factors

a Failure to check.
b Error judgement.

TABLE 12

11 COMPUTER INCIDENTS

Problems (4 types)

1 Not activated before the dive.
2 Battery became flat during the dive.
3 Diver unable to understand layout.
4 Diver unable to understand numerical data.

Major contributing factors

a Poor design.
b Lack of understanding.

should be equipped with either a low battery alarm or a mechanism by which the diver can test battery power before a dive. Computers should be used to assist dive planning and should not be the sole method of dive management. All divers using computers should dive with an additional timing device, depth gauge and a set of tables to calculate decompression requirements (if needed) even after surfacing when the computer failed. However, misreading dive tables also featured in the morbidity incidents reported to DIMS.

TABLE 13

9 DIVE TABLE INCIDENTS

Problem

9 cases Misreading.

Major contributing factors

a Lack of understanding.
b Poor design/layout.
  a Poor training.
  b Inexperience.

The increasing popularity of dive computers has resulted in less attention to dive planning and consultation with a set of diving decompression tables. However, diving decompression tables are difficult to understand and frequently errors are made during calculation of dive profiles and decompression requirements. This was clearly evident in the incidents reported here (Table 13). Basic education about inert gas uptake and elimination, necessary to the understanding of safe decompression and dive table theory, and the use of a dive computer to guide the dive plan are both important aspects of diver training. The rechecking of a computer dive plan with a set of recognised dive tables will only enhance the safety of the diver.

Analogue depth gauge inaccuracy is of concern (Table 14). Even when a depth gauge is first purchased, the accuracy of the gauge is not known. Once purchased, there is no current requirement for any recalibration. It is clear that recalibration of these gauges is required.

Surface signalling devices (Table 15) are important to prevent the loss of a diver on the surface. These devices must be able to be seen in rough seas and poor visibility conditions. 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 the reports received they are often invisible and failed to maintain their upright position in adverse conditions. These devices need to be made from a sturdy material and tested in all conditions before being sold. All divers should finish the dive with enough air remaining in their air cylinders to manage adverse surface conditions and to fill a safety sausage. Air management is a training and educational issue.

TABLE 14

9 DEPTH GAUGE INCIDENTS

Problems (4 types)

1 Inaccurate.
2 Maximum indicator stuck in analogue gauge.
3 Maximum depth indicator not zeroed before dive.
4 Depth indicator not zeroed at commencement of dive.

Major contributing factors

a Lack recalibration /servicing.
b Failure to check.

Any whistling device used must be powerful enough to attract the attention of all on the surface and be audible over the noise of a boat's engine. This would minimise the chances of a whistle signal being neglected by the boatman.

TABLE 15

8 SURFACE SIGNALLING DEVICE INCIDENTS

Problems (4 types)

1 Unable to inflate safety sausage because diver out of air.
2 Signalling device (whistle) not responded to.
3 Safety sausage not seen because of poor visibility, or rough conditions.
4 Safety sausage failed to remain in the upright position during use in bad weather conditions.

Major contributing factors

a Poor design/manufacturing material.
b Inattention.

TABLE 16

5 EXIT LADDER INCIDENTS

Problems

5 cases Sea conditions made it difficult to use ladder.

Major contributing factors

a Not familiar with diving conditions.
b Lack of dive planning.
c Weather conditions.

TABLE 17

4 LIGHT SOURCE (TORCH) INCIDENTS

Problems

2 cases Torch snagged on other equipment or between rocks.
1 case Flooded during use.
1 case Batteries became flat during use, unable to check battery charge before use.

Major contributing factors

a Poor design.
b Lack of pre-sale testing.

The reported problems with exit ladders (Table 16) at the end of the dive indicated that planning the exit was not part of these dive plans. Water entry and exit are important parts of dive planning. A bouncing exit ladder in rough sea conditions is an important but fortunately rare cause of diver harm.

Limited visibility diving requires the use of a primary and secondary diving torch (Table 17). The water and pressure resistance of any diving torch needs to be tested before sale. The addition of a battery power indicator would prevent power failure during a dive. If a piece of equipment is considered essential, it is reasonable that at least one level of redundancy (e.g. duplicate equipment such as a contents gauge, dive timer, depth gauge and torch) are needed.

TABLE 18

10 WET SUIT INCIDENTS

Problems (5 types)

1 Tightness causing difficulty with breathing.
2 New suit altered buoyancy, diver failed to adjust weights.
3 Inadequate thermal protection.
4 An old Lycra suit providing inadequate protection from coral/jellyfish stings.
5 Hood causing claustrophobic reaction.

Major contributing factors

a Lack of training.
b Inexperience.
c Failure to check.
d Anxiety.

An alteration in buoyancy (Table 18) occurs when a diver changes his/her wet suit, uses a smaller tank or adds a piece of equipment. This is a training and education issue. Wearing a poorly fitting wet suit (either too large or small) is either due to ignorance, inexperience or stupidity.

TABLE 19

2 J VALVE INCIDENTS

Problem

2 cases J valve in “on” position at commencement of dive.

Major contributing factors

a Lack of understanding.
b Inexperience.
c Failure to check.

Contributing factors

FAILURE TO CHECK

Failure to check was the most frequently reported error. Checking protocols for each piece of equipment should be emphasised during training. Divers then can, or should be encouraged to, use these protocols as a template to develop their own pre-dive check list which will be easy for them to remember and hence perform. A previous study

TABLE 20

2 SNORKEL INCIDENTS

Problems

1 case Flap valve absent.
1 case Unable to keep snorkel dry because of non functioning flap valve.

Major contributing factors

a Failure to check.
b Failure to understand equipment.

TABLE 21

5 MISCELLANEOUS INCIDENTS

Problem

1 case Surface floating line snagged around diver.

Major contributing factors

a Inattention.

Problem

1 case Shot line snagged around diver.

Major contributing factors

a Inattention.

Problem

1 case Scooter motor back-wash activated the purge valve on diver's octopus regulator causing an unnoticed depletion of the diver's air supply.

Major contributing factors

a Inattention.
b Failure to check.
c Failure to understand equipment.

Problem

1 case Weight belt snagged on knife during emergency ditching.

Major contributing factors

a Inattention.
b Inexperience.
c Error in judgement.

Problem

1 case Video camera altered diver's buoyancy to positively buoyant.

Major contributing factors

a Inexperience.
b Error in judgement.
c Poor dive planning.

demonstrated that divers, even when the number of errors were known with a set of equipment, failed to identify all of them.[25] Failure to check was frequently associated with haste, inattention, a lack of post-dive maintenance and a lack of, or poor, servicing.

The incidents reported highlighted that the following are not often checked:

1 the condition of the fin and mask straps;
2 that the weights are securely fastened on the weight belt ;
3 that the weight belt is the correct size without too much tongue overhang;
4 that the tank is securely fastened in the BCD or backpack;
5 that no piece of equipment will impede the safe jettisoning of a weight belt in an emergency;
6 that any piece of equipment which has been recently serviced is functioning correctly before using it diving;
7 that the emergency BCD dump valve is functioning;
8 that the BCD inflator is correctly attached;
9 the high and low pressure air hoses for leaks or areas of weakness;
10 the octopus regulator is secured in an accessible position;
11 that an independent redundant air cylinder and regulator is full and turned on and has enough air to enable the diver to ascend safely without missing any required decompression stops;
12 the condition of the mouth pieces (on both the regulator and BCD inflator) and these are securely fastened; and
13 there are no dangling pieces of equipment that may get snagged during the dive.

A pre-dive check should address these issues. A pre-dive checklist suggested from the first 1,000 DIMS incidents will be the subject of a future paper.

Anxiety was also a major contributing factor in many of the incidents. This has implications for diving medical fitness. An anxiety trait may predispose a trainee to panic. Some published data indicate that 39% of diving deaths were associated with panic.[26]

A lack of understanding of how a piece of equipment functions, inexperience and insufficient training are educational and training issues. Divers must be made to realise that neither an open water nor advanced diver qualification means they are qualified for all diving situations.

Inattention was usually associated with a failure to check during the dive, however, at depth it may be due to nitrogen narcosis or carbon dioxide retention due to a poorly functioning regulator.

DESIGN CHANGES NEEDED

Some of the incidents reported highlight poor equipment design. Co-location of the inflate and deflate mechanisms on the BCD's inflator hose is ergonomically poor. Inflate and deflate mechanisms need to be separated. Other BCD design changes proposed include:

1 a larger, more accessible emergency dump valve in all BCDs,
2 a cut off mechanism to the power inflator and
3 standardisation of positioning of controls and valves on BCDs.

Other equipment design changes proposed include:

1 a low battery alarm in all dive computers;
2 standardisation of the dive computer face layout;
3 an audible low pressure alarm in contents gauges and tank pillar valves.

Sturdier manufacturing materials are needed in the surface sausage signalling devices. Light sources need to pressure tested before being sold. It is also reasonable to argue that all battery powered equipment should have either a low battery alarm or a monitor that indicates battery status.

MISUSE OF EQUIPMENT

Equipment misuse has been cited as a contributing factor in some recreational diving fatalities.[1,2]

BCDs are used to adjust a diver's buoyancy during a dive. Over-inflation to help raise a heavy object (i.e. anchor) is an incorrect use of a BCD. These incidents invariably are associated with accidental dropping of the object causing a rapid and uncontrolled, Polaris type, ascent with subsequent morbidity. The lifting of a heavy object should involve planning and perhaps 2 divers. If anchor retrieval is required at the conclusion of the dive then it should be part of the dive planning.

Safe diving practice dictates the use of an alternative air source for the out of air situation.[22,23] This usually involves the addition of another 2nd stage, octopus, regulator to the diver's 1st stage so that one diver's air supply can be shared with the diver who is out of air. Using the octopus regulator in this manner allows a controlled ascent once one diver is out of air.[19]

To use this regulator to continue the dive when one diver is out of air is a misuse of the octopus regulator and is not safe diving practice.

Diving with a non-functional octopus regulator is an unsafe practice. This can result in what might have been a well managed out of air problem becoming a panic situation.

Occupational diving regulations specify that a compressor attendant is necessary for hookah diving. The attendant is necessary to ensure that exhaust fumes are not sucked into the compressor's air inlet and that the compressor does not run out of fuel and to deal with problems causing compressor failure or resulting from a dragging anchor. Diving without using a surface attendant has been implicated in many "hookah" diving deaths.[27] It is also an example of stupidity.

Fins are necessary for locomotion underwater. To choose a pair, that is too large has safety implications. The loss of fins has been implicated in some diving deaths.[1]

Conclusions

A meticulous pre-dive check, the use of back-up equipment, additions and alterations to equipment design and manufacturing materials, regular servicing, post dive maintenance, recalibration of all gauges and adherence to strict standard diving safety practice will minimise the effects of all these equipment problems.

Corrective strategies

The strategies proposed to reduce the occurrence and minimise the effects of these equipment problems are shown in Table 22 (pages 193-195).

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TABLE 22

SUGGESTED STRATEGIES TO MINIMISE OUTCOME ASSOCIATED WITH EQUIPMENT PROBLEMS

Equipment problems	Corrective strategies
Buoyancy Control Device	
Inflation mechanism failure.	Pre-dive check, Servicing, Maintenance.
The inflation mechanism was not connected.	Pre-dive check.
Spontaneous activation of the inflation mechanism	Redesign, Educate, Servicing.
Not knowing how to use oral inflator.	Educate.
Confusion between the deflate and inflate buttons.	Redesign.
The BCD leaked.	Pre-dive check.
The diver did not know how to deflate the BCD.	Educate.
The dump valve malfunctioned.	Pre-dive check, Redesign.
The BCD was uncomfortable to wear.	Pre-dive check, Educate.
When fully inflated the BCD restricted the diver's respiration.	Pre-dive check.
The BCD provided inadequate buoyancy.	Educate, Pre-dive check.
The BCD too large.	Pre-dive check, Educate.
Regulator	
Pre-dive checks and stage problems.	Redesign, Extra air, Good buddy diving, Pre-dive check.
Servicing and stage problems.	Pre-dive check, Servicing, Maintenance, Good buddy diving.
Mouthpiece problems.	Pre-dive check, Maintenance.
Incorrect connection.	Pre-dive check, Educate.
Contents gauge	
Inaccurate.	Recalibrate, Pre-dive check, Alarm, Good buddy diving Redundancy, Dive plan, Check during dive.
Unable to read.	Redesign, Pre-dive check.
Lack of understanding of the units used.	Pre-dive check, Educate.
Lack of understanding of a fluctuating needle.	Educate.
Weight belt	
Dislodged during dive.	Pre-dive check, Educate.
Dropped at exit.	Educate.
Forgotten.	Pre-dive check.
Snagged on other equipment.	Educate, Pre-dive check.
Weights fell out of BCD pocket.	Pre-dive check, Educate.
Position prevented emergency jettisoning.	Pre-dive check, Educate.
Alternative air source	
Inadequate air supply.	Pre-dive check, Educate.
Not turned on.	Pre-dive check.
Empty.	Pre-dive check.
Octopus second stage not working.	Pre-dive check, Servicing.
Difficulty in breathing from octopus.	Educate, Pre-dive check, Servicing.
Difficulty during emergency ascent.	Redesign.
Leaking.	Pre-dive check.
Mask	
Mask squeeze.	Educate.
Flooding.	Educate.
Dislodgment.	Pre-dive check.
Mask strap broke.	Pre-dive check.
Unable to clear.	Educate.

TABLE 22 (CONTINUED)

Equipment problems	Corrective strategies
Cylinder	
Fracture in new cylinder.	Servicing.
Not secured adequately in backpack.	Pre-dive check.
Tape left on pillar valve.	Pre-dive check, Educate.
Change to smaller cylinder caused problems.	Educate, Dive plan, Pre-dive check.
Fins	
Fin strap broke.	Pre-dive check.
Forgotten.	Pre-dive check.
Loose – incorrect size.	Educate, Pre-dive check.
Computer	
Not activated before dive.	Redesign, Redundancy.
Unable to understand faceplate layout.	Educate, Redesign.
Battery flat.	Alarm needed, Redundancy.
Compressor	
No attendant.	Safe diving practice.
Ran out of fuel.	Pre-dive check, Safe diving practice.
Contaminated air supply.	Servicing, Safe diving practice.
No bail out bottle used.	Safe diving practice, Educate, Extra air.
Hose kinked or ruptured.	Extra air.
Wet suit	
Too tight.	Educate.
Inadequate thermal protection.	Educate.
Inadequate protection.	Educate.
Hood causing claustrophobia.	Educate.
Depth gauge	
Inaccurate.	Recalibrate, Redundancy, Good buddy diving.
Maximum depth indicator stuck.	Pre-dive check, Recalibrate, Redundancy, Servicing.
Maximum depth indicator not zeroed before dive.	Pre-dive check, Recalibrate, Redundancy, Servicing.
Dive tables	
Misreading.	Educate.
Surface signalling device	
Unable to inflate device.	Pre-dive check.
Device not responded to.	Safe diving practice.
Not visualised in rough conditions.	Dive plan, Redesign, Change manufacture.
Did not stay upright in adverse conditions.	Change manufacture.
Exit ladder	
Sea conditions making it difficult to use.	Dive plan, Redesign.
Light source	
Flooded.	Test by manufacturer, Pre-dive check.
Battery flat during use.	Alarm needed.
J valve	
Turned on before dive.	Pre-dive check, Educate

TABLE 22 (CONTINUED)

Equipment problems	Corrective strategies
Snorkel	
Unable to keep snorkel dry.	Pre-dive check
Emptying flap valve not working.	Pre-dive check.
Scooter	
Depleted air supply.	Check during dive.
Surface line	
Snagged around diver.	Dive plan, Educate.
Knife	
Snagged weight belt.	Educate.
Video camera	
Changed diver's buoyancy.	Educate.
Shot line	
Snagged around diver.	Dive plan, Educate.

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