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AN EVALUATION OF BUOYANCY JACKET SAFETY IN 1,000 DIVING INCIDENTS.

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Abstract

There were 154 incidents involving buoyancy jacket use, misuse and malfunction in the first 1,000 incidents reported to the Diving Incident Monitoring Study (DIMS). Forty eight of these incidents involved morbidity. This is 10% of the total morbidity reported in the time period. The buoyancy jacket, or buoyancy compensating device (BCD), incidents included divers being unable to exhaust their BCD, others being unfamiliar with the use and operation of their BCD, confusion between the inflation and deflation mechanisms, spontaneous inflation of the BCD by a poorly maintained or faulty power inflator, failure of inflation mechanisms, leaks from BCDs and inflation hoses, inadequate buoyancy and inflation of the BCD restricting the diver's respiration. Appropriate preventive strategies include an emphasis on a pre-dive BCD check, increased separation of the deflate and inflate mechanisms, annual servicing and post-dive maintenance of BCDs, an accessible dump valve that will exhaust air at a rate at least equal to that of maximum inflation, an education program to accompany the purchase or hiring of a BCD and an emphasis on buoyancy control in diver training. In particular, trainees should be taught how 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.

Introduction

A buoyancy jacket, often called a buoyancy control device (BCD), is an important component of buoyancy control in diving. During the past 20 years, the use and design of BCDs has changed considerably. The "horse collar" style, which relied on oral inflation for surface buoyancy, has been replaced by a waistcoat style jacket that has both oral and power inflation mechanisms. These enable divers to adjust their buoyancy both on the surface and underwater. This style of BCD does however have the potential to change a diver's buoyancy and depth very rapidly. Consequently, it is not surprising that BCD problems have been cited as a cause of both morbidity and mortality in recreational diving.[1-3] In an analysis of 100 scuba diving deaths, BCDs were reported to be a major contributor to diving accidents.[3] These accidents were attributed either to an overinflation or to a failure of the inflation mechanism. However, this report lacked both objective data and a detailed analysis.

The safe use of any diving equipment is dependent upon an adequate knowledge of its function and the common problems encountered during its use. Identification of the common errors in the use of equipment may suggest corrective strategies based on a change in equipment design and should lead to the reduction or elimination of the effects of these errors.

Incident reporting is a study of error and unintentional events. It is a method of identifying, classifying and analysing error in the context of contributing and associated factors.[4,5] It is not a new concept, being first used during World War Two to improve military air safety[6] and now is an established part of safety in aviation,[7,8] the nuclear power industry[9] and anaesthesia.[5,10,11] The specific application of such an assessment to BCD use will identify common, as well as potentially dangerous, recurring errors and show where corrective strategies are necessary.

Method

A diving incident form was designed in 1988[12] and has since been modified. These forms have been 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 in 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. This allows for accurate reporting without personal identification and legal risk. Once reported, the data are collected and analysed and if any identifying feature is present, it is removed.

Data on all incidents associated with the use of a BCD in the first 1,000 diving incidents reported to the Diving Incident Monitoring Study (DIMS) were examined.

Results

There were 154 BCD incidents reported to DIMS in the first 1,000 incidents. Forty eight of these incidents resulted in morbidity (Table 1). These cases constitute 10% of the total morbidity reported in this time period.

The 79 incidents which were due to problems with

TABLE 1

48 CASES OF MORBIDITY ASSOCIATED WITH BCD INCIDENTS

Morbidity	Number
Decompression sickness	17
Cerebral arterial gas embolism	12
Pulmonary barotrauma	10
Salt water aspiration	4
Near drowning	2
Ear or sinus barotrauma	2
Not specified	1

TABLE 2

79 BCD INCIDENTS DUE TO PROBLEMS WITH THE POWER INFLATION MECHANISM

Problem	Number	Morbidity
The inflation mechanism failed	31	9
Confusion between the deflate and inflate buttons	25	10
Spontaneous activation of the BCD power inflator	15	6
Diver did not know how to use the oral or power inflator	7	2
Confusion between the inflate and deflate buttons	1	1
Total	**79**	**28**

TABLE 3

31 CASES OF INFLATION MECHANISM FAILURE

Cause	Number	Morbidity
The power inflation mechanism was not connected	11	2
A low air situation	5	3
The inflation mechanism jammed	5	1
The diver was unable to locate the inflator	5	1
An out of air situation	3	1
Inflator hose puncture	2	1
Total	**31**	**9**

the inflation mechanism are ranked in order of decreasing frequency in Table 2 and the causes of the underlying inflation mechanism failures are listed in Table 3. The remaining 75 reported BCD problems are listed in Table 4.

TABLE 4

MISCELLANEOUS PROBLEMS ASSOCIATED WITH BCD USE IN 75 DIVERS (EXCLUDING THOSE INCIDENTS THAT INVOLVED THE POWER INFLATION MECHANISM)

Problem	Number	Morbidity
Rapid ascent caused by a BCD problem.	73	37
BCD causing buoyancy problems at a "safety" or decompression stop	26	16
The BCD provided inadequate buoyancy	16	9
The BCD leaked	7	0
A problem was caused by inflation of the BCD at entry	5	0
The diver was unable to exhaust the BCD to abort the ascent after weight belt dislodgement	4	3
The air cylinder was not secure in the BCD's back pack	4	0
Dump valve malfunction	4	0
The BCD was too large or uncomfortable to wear	3	1
Inflation of the BCD restricted the diver's respiration	1	0
Total	**143**	**66**

Note that problems, and morbidity resulting, are not mutually exclusive.

The two most common factors contributing to the BCD incidents were failure to deflate the BCD (89 incidents, 41 of which caused harm) and divers not knowing how to use their BCD (71 incidents, 26 of which caused harm). The diving qualifications of the divers involved in the inflation BCD incidents are listed in Tables 5 and 6.

The factors contributing to the 89 incidents of inadequate BCD deflation and associated morbidity are listed in Table 7. In 40 of these incidents, the divers did not know how to use their BCD. The qualifications of these divers are listed in Table 8.

TABLE 5.

QUALIFICATIONS OF 89 DIVERS UNABLE TO DEFLATE THEIR BCDs

Qualification	Number
Diving student	6
Basic	14
Open water	38
Advanced	20
Divemaster	6
Diving instructor	1
Untrained	2
Not recorded	2

TABLE 6

QUALIFICATIONS OF 71 DIVERS WHO DID NOT KNOW HOW TO USE THEIR BCDs

Qualification	Number
Diving student	7
Basic	8
Open water	35
Advanced	12
Divemaster	4
Diving Instructor	1
Untrained	2
Not recorded	2

TABLE 7

CONTRIBUTING FACTORS AND MORBIDITY ASSOCIATED WITH 89 INCIDENTS INVOLVING INADEQUATE BCD DEFLATION

Contributing factors	Number	Morbidity
The diver was not familiar with the BCD's functions	40	20
Insufficient time to activate the deflate mechanism	26	12
The diver's buddy was unable to activate the deflation mechanism due to its inaccessible position	9	6
Maximum deflation rate was inadequate	6	1
Deflation mechanism inaccessible to the diver	5	1
Deflation mechanism was faulty	3	1
Total	**89**	**41**

TABLE 8

QUALIFICATIONS OF 40 DIVERS WHERE INABILITY TO DEFLATE THE BCD WAS DUE TO THE DIVER NOT KNOWING HOW TO USE THE BCD

Qualifications	Number
Diving Student	2
Basic	4
Open water	17
Advanced	10
Divemaster	3
Dive instructor	1
Not recorded	3

TABLE 9

CONTRIBUTING FACTORS IN 16 INCIDENTS WHERE THE BCD PROVIDED INADEQUATE BUOYANCY

Contributing factors*		Number	Morbidity
Low air situation		5	3
The diver did not know how to orally inflate the BCD	**	4	2
The power inflator was not connected	**	4	2
The dump valve malfunctioned	**	2	0
Out of air situation		1	1
The diver was unable to locate the inflation mechanism	**	1	1
The inflator hose was leaking	**	1	1
BCD provided inadequate buoyancy while retrieving the anchor		1	1
BCD leaking	**	1	0

*** These contributing factors are not mutually exclusive.**

**** Could have been prevented by a pre-dive check.**

The contributing factors in the 16 incidents (and consequent morbidity) in which the BCD provided inadequate buoyancy are listed in Table 9.

Thirty nine of the total 154 incidents could have been prevented if the divers had checked their BCD prior to diving. Eight of these preventable incidents caused harm to the diver. These incidents are listed in order of

TABLE 10

39 INCIDENTS WHICH COULD HAVE BEEN PREVENTED BY A PRE-DIVE BCD CHECK

BCD Incident	Number	Morbidity
Inflator hose was not connected correctly	11	2
Diver did not know how to orally inflate the BCD	4	2
Air cylinder was not secured in the BCD	4	0
Dump valve malfunction	4	0
BCD harness was not correctly fastened	3	0
BCD was an inappropriate size	2	1
Inflator hose was not secured in an accessible position	2	1
Deflation mechanism malfunction	1	1
BCD leaking	7	0
Leaking inflator hose	1	0
Total	**39**	**7**

decreasing frequency in Table 10.

In addition to the 154 reported BCD incidents, there were 9 “out of air” and 2 “low on air’ problems that were caused by the diver’s overuse of the BCD power inflator to maintain buoyancy. Four of these incidents resulted in morbidity.

Discussion

Incidents involving a BCD are frequently reported to DIMS and often cause harm. However, all of the incidents reported here could have been prevented by use of one or more of the following:

a the purchase or hiring of a BCD being accompanied by a relevant education program;
b changes in design of some BCDs and some features of all BCDs;
c a meticulous pre-dive BCD check;
d all introductory recreational diver training programs putting greater emphasis on the importance of buoyancy control;
e washing the BCD with fresh water after every dive;
f having the BCD serviced annually; and
g emphasising the need, and overlearning the correct way, to release the weight belt in an emergency.

These incidents and proposed corrective strategies are summarised in Table 11.

Having the power inflate and deflate mechanisms close to each other, as on all of the currently commercially available BCDs, is dangerous. This was demonstrated by the frequent occurrence of, and consequent morbidity from, incidents arising because a diver had difficulty distinguishing the inflate and deflate knobs. In addition, the often reported inability of a diver, or diver’s buddy, to activate either mechanism in an emergency suggests that these mechanisms should be separated and secured on different, but standardised, sides of the jacket. This would make them accessible during an emergency and it would improve the ability of divers to control their buoyancy. This is particularly important during an emergency air sharing ascent. Especially so if the second stage of the donor’s spare regulator is part of, or attached to, the BCD’s power inflator hose. The separation of the opposing functions would also mean that divers could be trained to inflate the jacket on one side and to deflate on the other, so reducing the risk of an error.

Inability to exhaust air from a BCD was not confined to the novice diver and was the main cause of morbidity in this study. These incidents were inevitably associated with a rapid ascent and often resulted from the diver either being unfamiliar with the use and functions of a BCD (this was not confined to novice divers) or confusion between the deflate and inflate buttons. In some cases, the error was failure of, or inability to locate, the deflate mechanism. Some incidents arose as a consequence of divers being unable to adjust their buoyancy adequately at a decompression or a “safety” stop.

Appropriate preventative strategies for all of these incidents include relevant educational programs (to accompany the purchase or hiring of a BCD), the separation of BCD deflate and inflate mechanisms, a change in BCD design to allow easier access to the deflate mechanism and an emphasis in recreational diving training programs on buoyancy control. In particular, the changes in buoyancy that occur in the last 4 m of an ascent must be emphasised, along with the specific teaching of techniques to slow an uncontrolled ascent.

The incidents of spontaneous jacket inflation were due either to poor maintenance or a design fault. These incidents could be minimised by:

a a meticulous pre-dive check of the power inflator;
b an accessible dump valve that is able to exhaust air at a rate at least equal to that of maximum inflation;
c addition of a cut off mechanism to the power inflator;
d annual servicing of the BCD;
e washing the inflator in fresh water after every dive ; and
f training programs stressing methods of slowing an uncontrolled ascent.

The 39 incidents that arose from, or involved, a “failure to check” indicate that a pre-dive BCD checking

TABLE 11

THE PROPOSED CORRECTIVE STRATEGIES.

BCD incidents	**Corrective strategies**				
The inflation mechanism failed	Checking			Buoyancy training	Washing
Confusion between the inflate and deflate mechanisms	Checking	Education	Design changes		
The power inflation mechanism was not connected correctly	Checking				
BCD inflation due to spontaneous activation of the BCD inflator	Checking		Design changes		Washing
The diver was unable to locate the power inflation mechanism	Checking	Education	Design changes		
The diver was unable to vent the BCD	Checking	Education	Design changes		
The diver was unfamiliar with the BCD's functions	Checking	Education			
The BCD provided inadequate buoyancy	Checking	Education			Servicing
The BCD leaked	Checking				
The BCD was too large or uncomfortable	Checking				
When inflated the BCD restricted the diver's respiration	Checking	Education			
Dump valve malfunction	Checking		Design changes		
The BCD caused buoyancy problems at a decompression or "safety" stop		Education		Buoyancy training	
Maximum deflation rate inadequate			Design changes		
The diver was not able to locate the deflate mechanism	Checking	Education	Design changes		
Leaking inflator hose	Checking				
The air cylinder was not secured in the BCD's backpack	Checking				

Description of strategies (in order of importance in prevention of BCD incidents).

Checking	A meticulous pre-dive BCD check.
Education	The purchase or hiring of a BCD being accompanied by a relevant education program.
Design changes	Changes in design of some BCDs and some features of all BCDs.
Buoyancy training	All introductory recreational diver training programs putting greater emphasis on the importance of buoyancy control.
Washing	Washing the outside of the BCD with fresh water after every dive.
Servicing	Having the BCD serviced annually.

protocol needs to be developed and taught to trainee divers. This inspection protocol should include a check that:

a there is no salt or debris encrusted on the power inflation mechanism;
b the inflator is connected;
c the oral and power inflation mechanisms work;
d the inflator hose does not leak;
e the inflator's mouth piece is functional;
f the inflator and deflator are secured and accessible;
g the BCD fully inflates and does not leak;
h the deflate mechanism works and no components are worn;
i the dump valve works;
j the air cylinder is secured in the back pack;
k the BCD is comfortable and all security belts are fastened; and
l when fully inflated, the BCD does not restrict respiration.

Eight incidents involved inadequate buoyancy on the surface and all resulted in morbidity. None of these divers removed their weight belt and in 4 of the incidents the diver did not know how to orally inflate the BCD. It is clear that the release of a weight belt and oral inflation techniques should be overlearnt in basic diver training programs.

There were 7 incidents in which the divers did not know how to inflate their BCD. These incidents would be prevented by thorough education and a pre-dive check.

Most power inflation failure incidents would have been prevented both by securing the inflator in an accessible position and a thorough pre-dive check. However, the highest rate of harm arising from power inflation failures was associated with either a low on air or an out of air situation and would have been prevented by appropriate air supply management.[13]

The reported incidents in which the diver overused the power inflator to maintain buoyancy and those in which the divers were unable to control their ascent after their weight belt became dislodged are indicative of divers using their BCD as their main, or even sole, means of buoyancy control. This is poor diving technique and can be avoided by better training. It is my opinion that the use of a BCD should only be taught after a diving candidate can demonstrate good buoyancy control in shallow water without the use of a BCD.

Conclusions

This study shows that BCD incidents are not uncommon in recreational diving and that BCD misuse is associated with a high incidence of morbidity.

An educational program should accompany the purchase or hiring of a BCD.

Modifications are needed in BCD design. The inflation and deflation mechanisms need to be separated and placed on either side of the jacket. All jackets should have an accessible dump valve that can exhaust air at a rate equal to that of maximum inflation.

Buoyancy training is an important aspect of recreational diving. Emphasis is needed on the predictable changes in ascent rate, especially in the last 5 metres of an ascent, methods that will decrease the rate of an uncontrolled ascent and on techniques of buoyancy control that do not rely on a BCD.

A BCD needs to be washed thoroughly with fresh water following use and serviced annually.

Recreational diver training should emphasise the importance of releasing the weight belt in emergency situations.

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