DECOMPRESSION SAFETY

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ABSTRACT

The risk of decompression sickness is a safety problem related to offshore diving operations. Modern safety management defines a systematic approach to such a problem based on policy edition, support from an organisation, planning and implementing, monitoring, reviewing and auditing. These activities are analysed in light of the experience of a large diving company, achievements are listed and areas of improvement are identified. It is shown that the next edition of decompression procedures will require hundreds of thousands of dive records to identify the critical factors, define models and validate new procedures. This exceeds the experience of a single diving company or even a single nation and it is believed that efforts of decompression sickness management should be co-ordinated at a European level.

INTRODUCTION

Decompression tables have been developed since the beginning of the century and have evolved to a point where the risk of decompression sickness (DCS) is considerably reduced. However, this risk cannot be completely ruled out. Considering the variations between individuals and worksite conditions, it must be admitted that a diver may develop symptoms during any given dive. DCS is a risk related to offshore diving operations that needs be recognised and managed as such.

Safety management, according to recent publications (1), is based on the following inter-related activities:

— definition of a policy,
— support from a competent organisation,
— planning and implementing,
— monitoring,
— auditing and reviewing.

It is reasonable to assume that the DCS risk can be managed on the same basis. An investigation is conducted using a large diving company's experience, such as the former Comex and the recent Stolt Comex Seaway, to identify and analyse these activities.

POLICIES

Diving companies that are successful in achieving high standards of health and safety have adapted policies which contribute to their business performances. It must be admitted that the attitudes towards DCS have evolved over the last 25 years from ignoring the problem to openly discussing the issue.

Twenty years ago, DCS incidence rates were neither monitored nor published except for military diving. Diving companies could not reliably assess the problem because the reporting systems were inadequate or because they employed free lance divers and could not follow up of their personnel.

Nowadays DCS incidence rates are monitored and published but there is still a lot of suspicion on the reliability of this data.

It is possible to suspect diving contractors of minimising the DCS incidents because the costs for the associated insurance coverage are high (2). However, I like to believe that it is not justified. First, there is a professional ethic built through organisations like AODC and DMAC. Second, there are elements of references, such as the statistics published by the HSE on air diving (3), and deviations from the industry's standards can easily be spotted. Finally, diving is a small world and facts that have been hidden come up sooner or later.

It is often suggested, especially among medical doctors, that figures are under estimated even if diving companies honestly report DCS cases. One claim is that the reporting systems are not reliable and that medical interviews often dig out new cases. This is a well recognised limit of administrative systems and it is accepted that direct contacts bring more information but we must work with it as it is all we have at the moment. Another claim is that the divers do not dare to report the DCS because they fear losing their jobs. Such cases must exist although the reasons for them could be diverse. Clearly, if the company policy is to fire a diver after the second DCS occurrence, this will not encourage reporting symptoms. Another reason could be that the diver wants to keep diving regardless of his symptoms and hide them to his employer. A last reason could be that the diver does not make the diagnosis of DCS. This is often the case with type II occurrences where symptoms are vague, such as fatigue or a headache, and often accounted for by the conditions of the dive.

However, it must be admitted that North Sea diving is not like Mediterranean sponge diving! Again, I like to believe that the company policies are reasonable, that the divers are sufficiently trained to recognise the symptoms of DCS and that mutual respect between supervisors and divers shall prevent this from happening.

It is sometimes suspected that some cases could have been reported for convenience. A particular worksite was investigated at Comex in 1977 where divers in saturation were paid on a daily rate and suspected to report "midnight bends", that were symptoms when close to the surface and late in the evening, the treatment of which would have added one day to the salary. Comparison with other worksites safety records proved that the hypothesis was not statistically valid.

Although the suspicion is still there, the policy is now to discuss DCS incidence rates openly. The main diving contractors publish DCS rates as part of their annual safety records and include them just like any other injury or illness in the H-values (frequency rates per worked million hours).

The policies have recently further evolved because of the increased importance of the individual susceptibility. The problem is the ageing of the offshore divers' population. Those divers who entered their career in 1972 aged 20 are now 41 years old and are more susceptible to DCS. There are good divers, and therefore highly demanded for saturation jobs, who are known to have niggles by the end of the decompression. Usually, they would be given systematically some hyperbaric oxygen on mask for a few hours by the LST's who have learned to deal with them and there will be no other consequence. This situation has evolved to the point that at Comex, in 1992, half of the individuals that presented symptoms of DCS had recurrent symptoms during another dive. On one hand, it means that if these divers were declared no longer fit to dive, the company safety records would improve by two thirds. On the other hand, the medical doctors have to weigh the risk of continuing diving and the dramatic changes in life style if the person suddenly lost his job as a diver.

This was illustrated in a study on saturation decompression carried out at Comex (4). On Figure No 1, measured rates of DCS incidence were plotted versus the rate of decompression. This allowed to identify an optimum rate of ascent for a given chamber PO_2 as predicted by the "critical volume" theory (5) which relates the critical size of a tissue gas bubble to the onset of DCS symptoms. The data also indicated that slowing down the decompression beyond this value would not significantly improve the safety. It seems that when the DCS incidence is less than 0.5 %, the safety performance of the procedures becomes biased by the individuals who use them.

When the incidents become less sensitive to the procedures or equipment than to the people, they cease to be a safety problem and become a medical problem. This is certainly the reason why saturation decompression safety records have stabilised to around 1%. The procedures have certainly improved but the policies have become more permissive. The problem is no longer a question of table but rather a matter of individual susceptibility. Like for long term effects, the point is to evaluate the effect but also to measure its impact on the person's quality of life (6), and this is the basis for future policies evolution.

ORGANISATION

The organisation allows for the policy to be put into practice. This is helped by the creation of a positive culture which secures the involvement and participation at all levels.

This culture can be simply field experience. Diving supervisors have played a very important role on the sites in the prevention of decompressions just by running prudent operations. It has been shown for instance with the US Navy tables, that supervisors have introduced systematic margins in the selection of the decompression schedules after they have learned empirically the limits of the tables (3).

Generally, this culture is the result of a more systematic approach based on prevention and precautions, using the classic triangle of equipment, training and procedures. Looking into the diving history, it is possible to identify three distinct periods, each with a different organisational approach to diving safety.

During the early 70's:
— Diving operations were mostly carried out in bounce diving,
— The procedures were based on the US Navy manual,
— The rate of DCS was high, presumably between 10% to 20% depending on depth,
— The medical doctors ruled the world,

Then came the North Sea construction phase:
— Saturation replaced deep bounce diving,
— The companies developed internal procedures,
— The rate of DCS was around 5%.
— Computer engineers ruled the world,

During the last decade:
— Saturation diving represents 80% of diving operations,
— There is a standardisation of diving procedures, the companies tend to use official tables, clients specifications or industry guidelines,
— The rate of DCS is around 0.5 % to 1% and does not decrease,
— Epidemiologists rule the world.

All these historical factors shaped the present DCS safety records. This can be illustrated by the development of the French official air tables, which were first introduced in 1974, were revised by Comex in 1986 (7) and were finally published after successful offshore validation in 1992 (8).

Table No 1 : Safety performances of the 1974 and the 1992 French official air tables measured on Comex worksites during in-water decompressions. Exposures are classified according to the Prt index defined by Dr. T. Shields (3).

Exposures	Prt<=25 (Moderate)		25<Prt<=35 (Standard)		Prt>35 (Severe)	
Tables	1974	1992	1974	1992	1974	1992
Dives	17,683	7,129	9,590	8,384	2,426	2,055
Type I DCS %	18 0.10%	1 0.001%	55 0.57%	12 0.14%	49 2.02%	17 0.82%
Type II DCS %	1 0.006%	0 0.00%	1 0.01%	1 0.01%	1 0.04%	2 0.09%

The company organisation has been successful and the improvement is significant but it must be recognised that the process was slow. It is clear that the diving expertise that was shifted from the Navies to the diving companies will have to be passed over to associations like the AODC, DMAC or EDTC if further improvements are to be achieved.

PLANNING AND IMPLEMENTING

Successful diving companies adopt a planned and systematic approach to policy implementation. Performance standards are established and performance is measured against them. The standard way of presenting performance in the industry refers to lost time and non lost time accidents but these terms require some clarification before they can be apply to DCS.

One possibility is to use the classification of DCS into type I (pain only) and type II (serious). This classification has been used by Dr. T Shields in his analysis of North Sea air diving operations (3). It allows ranking the DCS severity according to the consequences for the diver. Reference is made to the DMAC note No. 13 (9):

- a diver with type I symptoms successfully treated can resume diving after 24 hours,
- a diver with type II symptoms, even successfully treated, must have a medical examination before he is declared fit to dive again.

One alternative is to use a classic definition of the border between non lost time and lost time accidents that is whether the person can resume working during the next shift (1). It allows loosely classifying the DCS severity according to the situation:

- during a saturation decompression, a bend (almost always type I) would be treated as a non lost time accident because the diver would be sent ashore in any case after the end of the decompression.
- during air diving operations, type I symptoms successfully treated could be considered as a non lost time accident if it is noted that the diver is likely to work on deck for the next shift,
- or could be considered as a lost time accident if it is noted that the diver must wait 24 hours before he can resume diving.
- All other symptoms would have to be classified as lost time accidents because the diver is evacuated most of the time.

These different alternatives leave room for interpretation. The conventions used at Comex were a combination of the methods described above :

- type I DCS successfully treated is considered as a non lost time illness,
- all the other cases of DCS are considered as lost time illnesses.

Another difficulty with decompression performance standards is when few DCS are recorded. Recently, the divers onboard a Comex barge working back and forth over the UK-Norway border, reported that Norwegian decompressions were more comfortable than British decompressions (specific saturation procedures are used in Norway). Although fatigue is a subjective feeling and the cases reported were biased by many other observed differences in the operations, the point was taken seriously. The comparison of performances in term of recorded DCS incidents could not allow differentiating between the two procedures. Then fatigue was introduced as a second performance criterion and this helped modifying the company procedures (the chamber PO_2 was reduced from 0.6 to 0.5 bar during the ascent). Fatigue cannot easily be quantified and is more difficult to handle than a simple incidence rate but clearly, the reduction of DCS incidence will require sooner or later the definition of more sensitive performance standards.

MONITORING

Successful diving companies monitor their decompression safety performances. This reveals when and where action is needed to improve performance. This is the domain of excellence of databases.

The first databases were developed on diving reports collection and analysis. Comex set up a diving report database as early as 1975 that has evolved into a very efficient tool for the control, development and validation of procedures. It now contains over 150,000 dive reports (10). Other diving companies (11) and government agencies (3) have had the same initiative since.

The expected evolution of the diving databases is towards a higher scale to obtain access to a greater amount of divers' exposures. The last French air tables revision required the analysis of 65,000 exposures to reach a measured level of less than 0.3 % overall DCS incidence (8). The next revision of these tables will have to aim at less than 0.1 % DCS incidence over perhaps a wider range of depths and bottom times. To document that the new procedures are effectively better than the previous ones, an enormous amount of dives will be required, something like 500,000 divers' exposures. This amount of dives roughly represents 10 years of North Sea operations and will require an international co-operation.

Another evident evolution of databases is to store more information per dive. The trend is to seek information on all the depth variations during the dive (yo-yo diving, ascent for a tool, exact surface interval, etc.). The reason is illustrated on the very particular case of surface decompression using data published in North Sea operations and Comex operations (12). In-water and bell transfer under pressure (TUP) decompressions, which have rather smooth ascents, were compared in Table No. 2 to surface decompressions, which introduce an abrupt pressure change when the diver ascends to the surface before he is recompressed in the deck chamber.

The comparison of the type I DCS occurrences does not allow differentiating between the two techniques of decompression. However, the comparison of the type II DCS occurrences shows that their incidence becomes significantly much higher with the surface decompression than with in-water decompression (ten times more for standard exposures). Clearly, pressure changes play an important role in the decompression safety and they are worth monitoring.

Table No 2 : Comparison of air in-water and bell TUP decompressions with air surface decompressions (SDO). Exposures are classified according to the Prt index defined by Dr. T. Shields (3).

Exposures	Prt<=25 (Moderate)		25<Prt<=35 (Standard)		Prt>35 (Severe)	
Method	In-water Bell TUP	SDO	In-water Bell TUP	SDO	In-water Bell TUP	SDO
Dives	37,551	10,674	22,643	54,230	8,349	9,323
Type I DCS %	30 0.08%	4 0.04%	78 0.34%	118 0.22%	77 0.92%	87 0.93%
Type II DCS %	5 0.01%	1 0.01%	3 0.01%	74 0.14%	12 0.14%	35 0.38%

If present diving reports give indications on depth and time, the exact pressure profile can only be recorded with electronic dive recorders. The treatment of such numerous records will require a lot of computer power and fancy statistical tools. These future databases will be much more complex and expensive than the present ones based on diving reports and this again will require international co-operation.

AUDITING AND REVIEWING

Successful diving companies are able, by reviewing and auditing, to learn from all relevant experience and apply the lessons to operations. However, with DCS occurrences, the problem is identifying the relevant causes before a solution can be implemented and verified.

This is illustrated by the limitation imposed in air diving in the UK sector. The publication of the statistics of Dr. T. Shields has shown an alarming incidence of DCS for deep and long exposures (3). As a result, the Department of Energy issued a series of Safety Memorandums limiting air diving exposures in the UK sector (13). The review was based on the classic theory which assumes a direct dependence of the decompression safety to the amount of inert gas loaded in the diver's tissues.

This approach, purely based on a depth and time limitation, has shown to be relatively efficient but still cannot account for serious DCS cases recorded in the permitted area.

Another theory would lead to a different approach. In a paper published in 1971, Hills (14) was able to show, using an animal model, that DCS occurrences could change from type I to type II symptoms by changing from continuous decompression to surface decompression. This remarkable experiment demonstrated the existence of different mechanisms for type II DCS which was later accounted for by the arterial bubbles model (15,16,17). This model can be summarised as follows:

— bubbles are normally produced during a decompression in the vascular space, transported by the venous system and filtered out in the lung,

- in case a bubble crosses the lung and is injected into the arterial system, it is likely to reach a neurological tissue,
- the neurological tissue will act as a gas reservoir and the bubble will start growing, causing a major alteration of the blood supply, and finally ischaemia.

According to the arterial bubbles model, surface decompressions or yo-yo diving should favour the occurrence of serious DCS. The scenario is that the pressure change generates bubbles and that the recompression may facilitate their transfer through the lung, following the bubbles size reduction according to the Boyle's law. It then becomes possible to draw a different scenario explaining the same depth and time distribution of DCS recorded for air diving. See figure No 2. This would support other preventive measures, such as recommendation on diving procedures rather than on dive exposures.

This process of review and feed back is highly dependent on the assumptions picked up for explaining the situation. This is its weakness and this is why the audit function comes in, which basically uses the principle of the "new eyes and fresh mind". Different persons with different experiences will react differently to the data. Richness of sensibility will produce a large variety of possible explanations which are likely to accelerate the learning curve. Comex has always published the results of its database. The audit principle recommends that databases supported by government agencies should also be published. If available, the information would allow the diving community to generate new ideas and test new models faster.

CONCLUSION

All the steps required for modern safety management have been identified in the historical development of safe decompression procedures, although the emphasis has changed with time.

Changes in attitude towards DCS are reflected by the policies. Now that the risk of DCS is small, the trend is to adopt a long term view. The emphasis has moved from the safety side to the health side. The present worry is less the procedures than the ageing divers who become more susceptible to DCS.

The monitoring function seems to be the most critical activity, because it is the one feeding the raw information for future studies. DCS incidence rates are low and large amounts of dive records will be required to document any changes in the procedures. This amount of data already exceeds one single company experience. The scale is now the one of North Sea operations.

The future of decompression procedures depends greatly on the European countries capacity to co-operate : standards for data collection must be defined, databases must be implemented and linked, and funds must be secured. It is hoped that organisations such as the EDTC will be able to initiate this co-operation and provide the basis for the next quantum leap. After the medical doctors, the computer engineers and the epidemiologists, it might be the time for the diplomats !

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Figure No 1 : DCS incidence rates measured during 5744 Comex saturation decompressions were plotted versus the mean rate of decompression (0.6 bar PO_2 in the chamber). An optimal rate of ascent was identified at around 40-45 minutes per meters. Slower decompression rates failed to significantly improve the decompression safety.

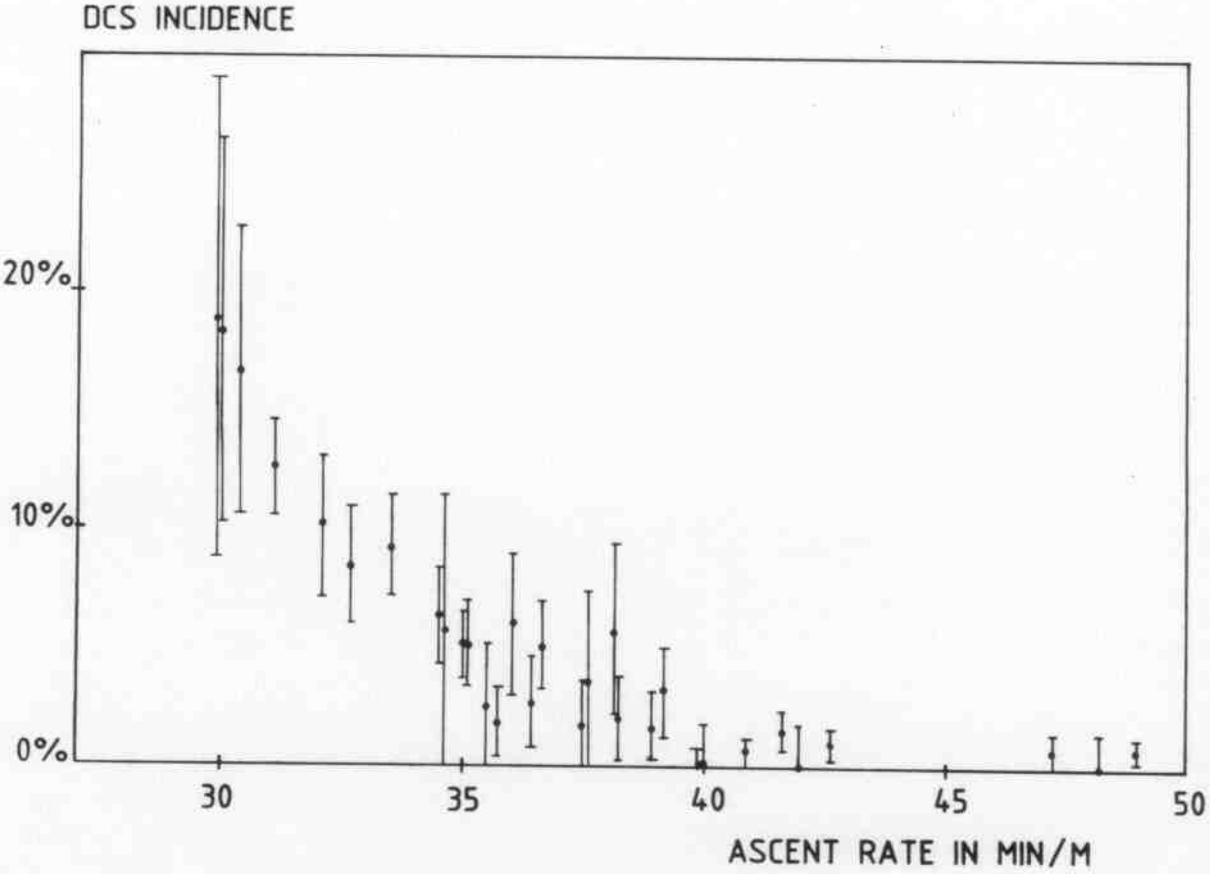

Figure No 2 : A possible scenario explaining the time and depth distribution of DCS in air diving operations in the North Sea (3). It uses the model of arterial bubbles where pressure changes are made responsible of type II DCS (12).

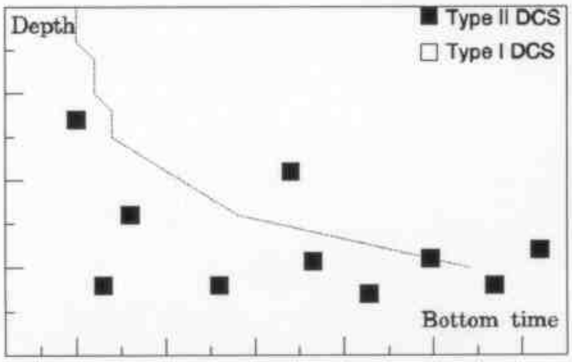

Fig. 2a : Type II DCS is first produced by yo-yo diving. These cases depend neither on the decompression technique nor the table but on the dive procedures. They are randomly distributed with perhaps a higher concentration close to the surface due to the increased importance of the Boyle's law.

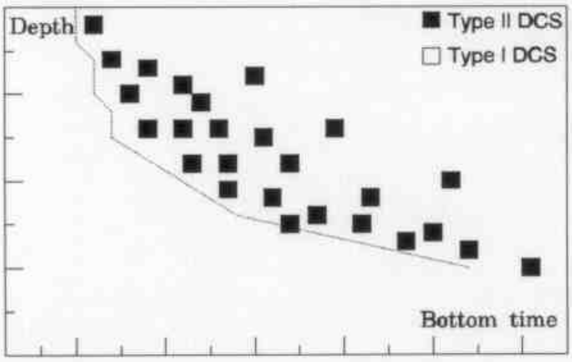

Fig. 2b : Type II DCS is then specifically produced by the surface decompression associated to severe exposures. A cluster appears beyond a sort of "natural" safe limit.

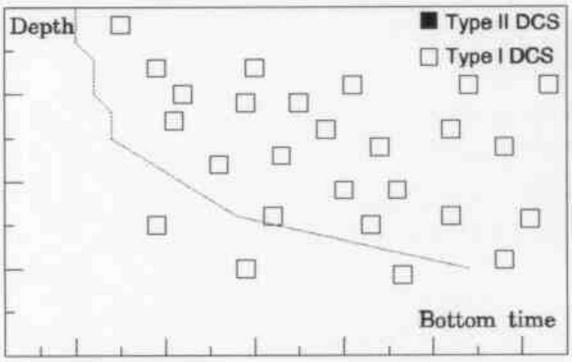

Fig. 2c : Type I DCS is only related to the severity of the exposure, i.e.; the tissue gas load. The cases do not depend on the decompression technique used. The more severe the exposure, the higher the number of cases recorded.

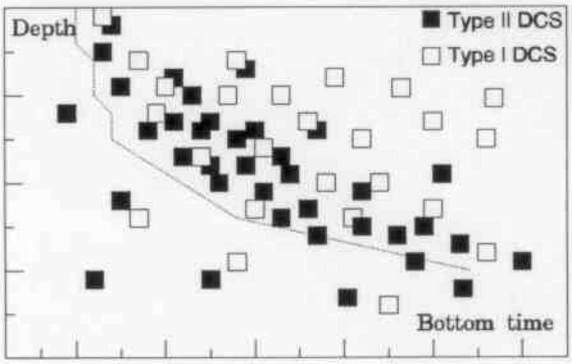

Fig. 2d : This figure summarises the various DCS cases of the figures 1a, 1b and 1c in the same diagram. It resembles the actual North Sea DCS pattern for air diving.