Health and Safety Executive

Time to treatment for decompression illness

Prepared by **North Sea Medical Centre**
for the Health and Safety Executive 2007

RR550
Research Report

HSE

Health and Safety Executive

Time to treatment for decompression illness

Dr Werner Stipp
North Sea Medical Centre
3 Lowestoft Road
Gorleston on Sea
Great Yarmouth
Norfolk NR 31 6SG

Hyperbaric oxygen treatment (HBO) is the standard and definitive treatment for divers with decompression illness (DCI). There is conflicting evidence in the medical literature on whether DCI is more responsive to early rather than late treatment with hyperbaric oxygen (HBO). The main aim of this study is to investigate the influence of time to treatment with HBO in divers with neurological DCI.

Here we show that early HBO treatment in divers with neurological DCI is robustly associated with a better outcome. There is a suggestion in this study that divers with DCI are less responsive if HBO treatment is delayed for 350 minutes or more (or approximately six hours) after surfacing from the incident dive. An interesting observation in this study is that if normobaric oxygen is administered before HBO, it tends to protect divers against delay in treatment with HBO. An additional analysis provides medical evidence that time limits for HBO as specified in the current ACOP[1] should remain in place.

This study recommends that a time to treatment action plan (TTT action plan), which specifies what to do when a diver develops suspicious DCI symptoms, will help to ensure that divers have prompt HBO treatment. Divers with serious DCI should be given the appropriate level of medical care in a hospital setting.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

---

[1] ACOP: Approved Code of Practice for Commercial Diving Projects for Inland/Inshore Diving (1998) under the Diving at Work Regulations 1997

HSE Books

First published 2007

EXECUTIVE SUMMARY

Hyperbaric oxygen treatment (HBO) is the standard and definitive treatment for decompression illness (DCI). HBO involves the delivery of 100% oxygen inside a treatment chamber at a pressure of more than one atmosphere.

Normobaric oxygen means administration of 100% oxygen at atmospheric pressure with tight fitting mask, ideally with a reservoir bag or a demand system, to a patient (diver). Normobaric oxygen should never be regarded as a substitute for HBO in divers with DCI.

There has been some debate regarding the relative importance of speed vs. quality of treatment for divers with decompression illness (DCI) arising from diving at work operations. Although there is consensus amongst diving doctors that there is no substitute for quality supportive medical care in a seriously injured diver, there is conflicting evidence in the medical literature on whether DCI is more responsive to early rather than late treatment with hyperbaric oxygen (HBO). The main aim of this study was to investigate the influence of time to treatment with HBO in divers with neurological DCI.

The Health and Safety Executive's Approved Code of Practice (ACOP) for Commercial diving projects inland/ inshore under the Diving at Work Regulations, 1997 provides guidelines regarding the availability of hyperbaric chambers to ensure prompt treatment in the event of a diver developing DCI. The guidance states that a compression chamber should be within 2 hours travelling distance for dives over 10 and up to 50 metres with either no planned in-water decompression; or with planned in-water decompression of up to 20 minutes. For inland/ inshore diving with no planned in-water decompression, and if the diving depth is less than 10 metres, the ACOP states that the compression chamber should be within 6 hours travelling distance from the diving site. For dives with planned in-water decompression greater than 20 minutes, a compression chamber is required on site.

Firm medical evidence is needed to allow the HSE to review, and if necessary amend the current guidance in this area.

This study provides evidence that early HBO treatment in divers with neurological DCI is associated with a better outcome. An additional analysis evaluating the current ACOP provides evidence that divers who are compliant with the ACOP, i.e. divers with DCI having HBO within the time limits specified above (see above), have a better outcome when compared to divers who are non compliant. This study therefore provides medical evidence that the time limits as specified in the current ACOP should remain in place.

An interesting observation in this study is that normobaric oxygen administered to the diver before HBO tends to protect the diver against a delay in treatment with HBO. There is a suggestion in the analysis of this study data that divers with DCI who did not receive normobaric oxygen are less responsive to HBO treatment after 350 minutes (or approximately six hours) of surfacing from the incident dive.

Diving contractors and diving supervisors, professional and amateur divers, as well as medical staff, need to be informed and educated on the importance of early hyperbaric oxygen treatment in divers with DCI.

The author recommends that a revised ACOP should re-emphasize the importance of administering normobaric oxygen in divers who develop symptoms and signs suggestive of DCI.

Of note is that HBO gives complete resolution of DCI in the majority of DCI cases (relatively few divers had residual symptoms or signs of neurological DCI after all HBO sessions). Prompt HBO will result in earlier resolution of DCI symptoms and signs.

Knowledge of symptoms and signs of the illness in amateur and professional divers are important, but according to research are not sufficient to change patient behaviour to ensure that patients seek specific treatment at an early stage. A well laid out *time to treatment action plan (TTT action plan)* on what to do when a diver develops suspicious symptoms will be more effective in ensuring divers seeking prompt HBO treatment. It is recommended that a *TTT action plan* should be included in each diving plan. Transport arrangements need to form part of a *TTT action plan.*

The questionnaire used in this study could form the basis of the development of a clinical diving incident reporting system to the HSE which could be undertaken by doctors with medical responsibility for diving operations. Such a reporting system may help the HSE to identify diving operations/ practices that have a high incidence of DCI (and a poor response to HBO treatment) which in turn could be used to initiate preventative action. The time taken to HBO treatment could be included in each incident report.

Further research is necessary to identify divers who are more susceptible to DCI at the pre-employment medical.

CONTENTS

ACKNOWLEDGEMENTS

Dr Nick McIver for his advice and support throughout the project.

Dr Phil Bryson, Marguerite St Leger Dowse and the Team at DDRC for their excellent work.

The Directors of Abermed, Phil Smith and James Miller for their support.

Dr Andrew Lynch of Cambridge University Technical Services Ltd for statistical advice.

1. BACKGROUND

The UK Health and Safety Commission (HSC) and the Health and Safety Executive (HSE) are responsible for the regulation of risks to health and safety arising from work activity in Britain. The objective of this work was to provide medical evidence to uphold the mission of the HSC and HSE, which is to ensure that the risks to people's health and safety from work activities, in this instance from diving activity at work, are controlled. An adverse health effect of diving activity is development of acute decompression illness (DCI). Neurological DCI could result in permanent disability or loss of function. It is therefore extremely important to provide a scientific evidence base of the influence of factors that could prevent divers from developing decompression illness and eliminating/ minimizing the consequences of DCI in a diver once the symptoms and signs are present.

There is conflicting evidence in the medical literature on whether DCI is more responsive to early rather than late treatment with HBO[4-13]. There has also recently been debate regarding the relative importance of speed versus the quality of treatment for DCI. The ideal statistical model that investigates time to HBO will also incorporate other treatment modalities such as IV fluids and normobaric oxygen administration as these may give indications on the relative importance of speed vs. quality of treatment.

The Health and Safety Executive's Approved Code of Practice (ACOP)[1] for Commercial diving projects offshore under the Diving at Work Regulations, 1997 states that an on-site hyperbaric chamber should be available for offshore diving operations. The Approved Code of Practice (ACOP) for commercial diving projects inland/ inshore[2] states that a compression chamber should be within 2 hours travelling distance for dives over 10 and up to 50 metres with either no planned in-water decompression; or with planned in-water decompression of up to 20 minutes. For inland/ inshore diving with no planned in-water decompression and if the diving depth is less than 10 metres, the Code of Practice states that the compression chamber should be within 6 hours travelling distance from the diving site. For dives with planned in-water decompression greater than 20 minutes, a compression chamber is required on site.

Although these time limits are laid down in the aforementioned ACOP, there is a need for medical evidence to support the ACOP or to be taken into account when reviewing the ACOP.

There is consensus amongst medical professionals that there is no substitute for hospital based quality supportive treatment in a diver suffering from serious DCI.[3] This type of treatment could only be delivered by selective medical expertise and includes modalities such as central venous lines, inotropic support and treatment of refractive seizures, to give some examples. There several are obstacles to overcome as diving activity is done in remote and inaccessible areas where the medical expertise is only available by phone. A decision where treatment to a centre where aforenamed quality care could be delivered, balanced against the benefits of prompt definitive hyperbaric treatment will need the back up of good scientific evidence, which was the purpose of this study.

The broad aims of the project were therefore:

1. To review the current literature on the relative importance of time to HBO treatment versus the quality of treatment on the outcome of DCI cases.

2. To carry out statistical analysis on the available data regarding the outcome of HBO treatment for DCI cases with specific reference to the time between surfacing from the incident dive, and the start of HBO treatment. These data will be drawn from existing records at two hyperbaric centres in the UK, which regularly treat commercial and recreational divers.

3. To make recommendations as to what changes (if any) are needed to current guidance regarding the availability of compression chambers, referring to the current ACOP's for inland/ inshore diving for work purposes.

1.1 STUDY OBJECTIVES.

1. To assess whether, and if so to what extent, the time to HBO treatment (time from surfacing after the incident dive) would influence the outcome in divers with acute neurological DCI after the first HBO session and after all HBO sessions.

2. To assess the effect of normobaric oxygen administered to acute neurological DCI cases, on the outcome of these cases, before they had the first HBO treatment session.

3. To assess the effect of IV fluid administration to acute neurological DCI cases, on the outcome of these after the first and after all hyperbaric treatments.

1.2 TIME TO TREATMENT WITH HYPERBARIC OXYGEN (A THERAPEUTIC DIVING TABLE) AND QUALITY OF HYPERBARIC TREATMENT, A LITERATURE REVIEW.

The question of whether early treatment of DCI with hyperbaric oxygen improves the clinical outcome remains unanswered. There is an impression amongst diving physicians that DCI is more responsive to early rather than late HBO treatment. There is contradictory evidence of the responsiveness of DCI to early HBO treatment in the literature (refer to table I): The benefit of prompt HBO treatment was described by Rivera in 1964.[4] Rivera presented the outcome as "relieved, recurred and residual" after the first HBO treatment and "total relieved" and "total residual" after further HBO treatments. The effect of time to HBO was evident in his study as the proportion of cases that were "relieved" after one and all HBO treatments respectively were 9 1.4%, 97.7% (N=175) for cases treated within 15 min; 85.5%, 95.5% for cases treated within 3 to 6 hours (N=172); 76.9% and 86.8% (N=91) for cases treated within 7 to 12 hours; 57.2% and 57.1% (N=7) for cases treated within 49 to 96 hours; and 0% (N=2) for cases treated within 97 to 144 hours. His cases also include skin DCI (14.9%) and respiratory DCI (2%). He commented that civilians adhere to a lesser extent to US Navy diving tables than military divers. Rivera used the time interval from the diver becoming symptomatic until the diver entered the chamber for HBO treatment in his study. The proportion of cases that had residual effects after one and after all HBO treatments were 1% and 2% (N= 175) for cases treated within 15 min, and 100% and 100% for cases treated within 96 to 144 hours (N=2). There is therefore a clear relationship between improved outcome and earlier HBO treatment.

Rivera recommended that a diver should be kept in the vicinity of a hyperbaric chamber after a dive for at least 24 hours.

Kizer did a retrospective review of 50 cases of divers diving around the Hawaiian Isles in 1982.[5] He divided cases as mild or pain only decompression sickness and serious decompression sickness. Delay to treatment was divided into a 12-24 hour group, and a more than 24 hour group. Of the severely affected cases 84% of the 12-24 hour group had a complete recovery whilst 54% of the more than 24 hour group had a complete recovery.

Van Hulst[6] reviewed 121 cases that occurred between 1979 and 1989 at the Diving Medical Centre in the Netherlands. Seventy-seven cases were classed as Type II DCI. HBO treatment within 12 hours resulted in complete recovery in 34 cases (77%). Delay in treatment by more than 24 hours (n=14) resulted in 43% recovery.

Rudge and Shafer[7] investigated the effect of delay on treatment outcome in altitude-induced decompression sickness. They concluded that patients successfully treated by a single HBO course presented earlier (mean 10.6h) than patients who failed to resolve after HBO (mean 1 8.2h).

Vann studied the effect of flying on diving on 1159 decompression sickness incidents of the Divers Alert Network (DAN) database from 1987-1 990.[8] In the univariate analysis applied to the DAN data long delays was associated with less successful initial decompression and a higher incidence of residual symptoms. On controlling for confounders with logistical regression this association between treatment delay and initial recompression disappeared, and the association between treatment delay and residual symptoms after three months became weak. Vann commented that omission of confounders could lead to spurious associations in time to HBO treatment studies.

Ball studied 49 cases of spinal cord DCI at the US Navy base at Subic Bay in the Philippines.[9] All these cases made long, deep dives with home made surface supplied air/ gas. Sixty-five of the 112 case records were incomplete, 16 cases diagnosed with cerebral arterial gas embolism (CAGE) were excluded. Ball divided the delay in treatment in groups of less than 12 hours, 12-24 hours, and more than 24 hours. He used a scoring system previously published by Dick and Massey[10] to document the response to treatment. Ball concluded that early treatment (within 12 hours) is beneficial for severely affected cases (p=0.008). If all the cases studied were taken into account, time to HBO treatment did not make a significant difference in the outcome (p=0.229). Due to the small number of cases in his study, he was unable to comment on moderately affected cases. Most of his cases were classed as having severe spinal DCI; 67% required retreatment.

Boussuges[11] states that the delay between emerging from the water and compression did not differ significantly (p=0.44) amongst divers with or without sequelae. The main aim of his study was to develop a gravity score to assess the efficacy between different hyperbaric treatments. He used 96 scuba divers that had DCI to develop the gravity score and validated the score with 66 divers from a different hyperbaric unit. AGE cases were excluded from the study. The outcome of his study was sequelae after all HBO treatments.

Desola[12] studied 466 cases that had a "dysbaric disorder" following a prospective model. Outcome was classed as "satisfactory". Neither bivariate nor multivariate analysis revealed any relation between the number of hours delay and the initial, medium and final outcome. Desola's study concluded that dysbaric disorders are more responsive to HBO treatment in the first minutes rather than after hours had elapsed.

Ross[13] performed a clinical audit on divers that had HBO in Scotland between 1991 and 1999. Time to HBO treatment after symptom onset was not statistically significant in influencing the response to initial HBO (N= 166) and did not increase the probability of a poor condition on discharge (N=165). Ross concluded that the major determinants of outcome were professional diver status and severity of presenting illness. Patients with more severe DCI had earlier treatment in his audit, this was considered to be a major confounding factor when assessing the influence of time to HBO therapy on outcome of DCI.

Time to HBO treatment as well as selecting the appropriate hyperbaric facility needs to be considered when planning on how to manage diving emergencies of a diving project. Selecting the appropriate chamber to match the severity of a patient's clinical condition is a two-way selection process with the referring authority choosing a chamber and the chamber operators advising on the suitability of their facility for the patient[3]. This selection process is the responsibility of the referring clinician who made an assessment of the clinical state of the patient and needs to feel comfortable that the receiving chamber has sufficient capability to treat the specific patient. A document categorizing the level of medical care provided by hyperbaric chambers has been published by the Faculty of Occupational Medicine[3]: A category 1 hyperbaric chamber should be capable of receiving patients who may require advanced life support either immediately or during hyperbaric treatment; Category 2 chambers should be capable of receiving patients from any diagnostic category where the patient is not likely to require advanced life support during hyperbaric treatment. Category 3 chambers should be capable of receiving emergency cases of divers and compressed air tunnel workers where the patient's condition requires immediate hyperbaric treatment. Category 4 chambers should be capable of receiving emergency and elective cases of patients of any diagnostic category who are not likely to require access during hyperbaric treatment.

Patient transfer is a critical factor in the quality of the hyperbaric medicine service provided affecting the outcome of patients as patients needs to be transferred promptly to the appropriate hyperbaric facility for treatment. A clinical audit undertaken by the specialist centre in Scotland suggests that the most severely ill patients benefit from direct transfer to a specialist centre in Aberdeen where the appropriate supportive medical care is available[13]. Arrangements regarding patient transfer needs to be made beforehand for a specific diving operation to ensure rapid access to a hyperbaric facility in the case of a diving emergency.

Table I Time to hyperbaric treatment: a literature review.

Author	Subjects	Number of outcome possibilities	Flying after diving considered?	Initial severity included in the analysis?	Results/Comments.	Time interval used.	Time to HBO: Significant effect shown?
Rivera[4] 1964	847 DCI cases, US Navy & Civilian Florida USA, 1946-1961	5 (relieved, recurred, residual after the first and residual and relieved after all HBO treatments)	No	No	Large study population, 78% of cases treated within 6 h.	Symptom Rivera's onset to HBO	**YES**
Kizer[5] 1982	50 DCI cases, 52% sport diving, Hawaii, 1976-79	4 (complete, substantial, moderate & minimal recovery)	No	Yes	84% of severe cases recovered in 12-24h group, 54% recovered if delayed >24h	Symptom onset to HBO	**YES**
Van Hulst[6] 1990	121 DCI cases, Navy & Civilian, Netherlands Navy, 1979-89	3 (cured, mild rest symptoms, severe rest symptoms)	No	No	7% complete recovery if treated within 12 h, 43% complete recovery if >24h delay	Symptom onset to HBO	**YES**
Rudge, Shafer[7] 1991	233 altitude induced DCI, USAF, Texas 1984-88	4 (successful treatment, lack of symptom recurrence)	Not applicable.	No	Successful treatment delayed 10.6h, failed treatment delayed 18.2h ($p<0.05$)	Symptom onset to HBO	**YES**
Vann[8] 1993	1159 DCI amateurs, DAN 1987-1990, 120 facilities North, Central America, Carribean	4 (successful initial recompression, residual symptoms 3 months after treatment)	Yes	No	Long delays associated with less successful initial recompression with univariate analysis, using logistic regression this relationship became non existent & weak when assessing outcome after all HBO sessions. Time delay significant for residual symptoms only. ($p=0.0346$) . 16% of cases treated within 6 h.	Time from surfacing to HBO.	**YES**

Table I Time to hyperbaric treatment: a literature review.
Continued from previous page

Author	Subjects	Number of outcome possibilities	Flying after considered?	Initial severity in the analysis?	Results/Comments.	Time interval used.	Time to HBO: Significant effect shown?
Ball[9] 1993	49 DCI cases, Subic Bay, Phillipines	10 (1-3: mild; 4-6: moderate; 7-10: severe)	No	Yes	Response to HBO is significantly different among initial severity groups (r=0.88). Delay worsens outcome in severe cases (p=0.008).	Symptom onset to HBO.	**YES**
Boussuges[11] 1996	96 DCI cases in SCUBA divers, Salvator Hyperbaric Centre, France, 1985-1993	2 (with/ without sequelae after all HBO sessions)	No	No	Biased towards spinal cord disease. Did not use USN 6 table for treatment.	Time from surfacing to HBO.	**NO**
Desola, Sala, Bohe, et al [12] 1997	466 DCI cases, 1969-1995, Barcelona Spain	2 (Satisfactory/ unsatisfactory)	No	No	More dependant on the first few minutes than on the quality of treatment Time not significant in neither bivariate nor multivariate analysis	Symptom onset to HBO	**NO**
Ross[13] 2000	1st HBO: 166 DCI cases Discharge: DCI cases 165 1991-1999, Scotland	2 possibilities in each analysis (a poor response to initial HBO therapy/ a poor condition on discharge)	No	Yes	The time taken for the severely ill group is significantly less than for the mild/ moderate group. (Mann-Whitney, p<0.001) Outcome depends on professional status and severity of illness.	Symptom onset to HBO.	**NO**

2. STUDY DESIGN

This is a retrospective clinical outcome study of divers with acute neurological DCI, who had HBO treatment at the McIver Hyperbaric Unit of the North Sea Medical Centre in Gorleston on Sea, Great Yarmouth, UK (NSMC), and at the Diving and Diseases Research Centre's Hyperbaric Unit in Plymouth, UK (DDRC).

2.1 STUDY DESIGN

A validated and previously published scoring system[14] (Appendix 1) was used to assess pre- and post treatment severity of neurological DCI in divers who had undergone HBO therapy. By allowing for possible confounding factors, the relationship between the time delay to the first HBO session in minutes and the change in score was assessed. The confounding factors that were included in the model were age, gender, diver status (professional/ amateur), diving depth, dive duration, rapid uncontrolled ascent, repetitive dive and whether normobaric oxygen or IV fluids were administered.

As high altitude flying is likely to precipitate or aggravate DCI[15], divers that flew with a fixed wing aircraft after diving and before HBO treatment were excluded from the study. Flying at a low altitude with a helicopter did not exclude a diver from the study. There may be some instances where divers did not respond to HBO treatment and are referred to a specialist who diagnosed another neurological condition such as carpal tunnel syndrome or a radiculopathy due to cervical spondylosis. Such cases confirmed not to be DCI were excluded from the study.

Data from 160 cases of neurological DCI were collected from the McIver Hyperbaric Unit. These cases of neurological decompression illness had treatment with hyperbaric oxygen between 1 January 1986 and 31 December 2002 at the Unit. One hundred and thirty three cases from the McIver Unit. Two hundred and twelve cases form the DDRC unit met the inclusion criteria for the study. The data from these two Units were analyzed separately and as a whole.

A web interface was set up to collect the inter observer correlation data. Ten percent of randomly selected cases were selected from the DDRC database of DCI cases who met the inclusion criteria for the study. The two diving physicians who collected the data were blinded for each other's observations and only the scores before and after the first hyperbaric treatment were evaluated.

2.2 COLLECTION OF DATA

2.2.1 The study questionnaire.

The scores were determined by diving doctors examining divers' records using a validated questionnaire[14] (see Appendix 1) designed for the purpose. In this way the recovery from functional limitations caused by DCI in divers could be assessed. The same validated scoring system was used to assess the initial severity of neurological DCI before HBO therapy. The investigator used the above diving medical records, as well as the typed diving incident reports that are usually sent to the divers' General Practitioner, to determine a neurological score before and after HBO. The questionnaire used had 25 questions reported as seven subscores of neurological systems. The seven neurological systems assessed were: pyramidal (1), sensory (2), cerebellar (3), bladder and bowel function (4), vision (5), mental function (6) and brainstem (7).

2.2.2 Inter rater agreement.

Different investigators collecting the information from the records might vary in what they perceive. A random sample of divers' records was therefore used to assess the inter-observer reliability of the investigator against an experienced diving doctor. The inter-observer reliability of the investigators was assessed through calculation of an interclass correlation coefficient. Around 10-20% of the cases included in the study were randomized and analysed for this purpose.

3. RESULTS

Presented here is an analysis of two sets of data of DDRC and NSMC, each detailing the characteristics and responses of divers who received hyperbaric oxygen (HBO) treatment. The purpose is to determine a) whether the two data sets can be combined, b) what underlying structures there are in the data, c) determine whether the current guidelines on time to treatment are backed up by the data, d) to model the associations with time to treatment in a more general manner and e) whether application of normobaric oxygen prior to HBO is beneficial. All analyses were performed using the R 2.3.1 software package.[16] The South West Devon Research Ethics Committee gave ethical approval for this study.

3.1 ASSESSMENT OF INTER-RATER AGREEMENT

59 records were assessed by more than one rater. 38 by two raters from the NSMC, and 21 by one rater from each of DDRC and NSMC. From each record, the severity scores before and after treatment were assessed, using the questionnaire of appendix 1. Of primary interest is that there is no bias between raters (particularly those from different centres). Secondary points of interest include assessing for any trends in differences of rating, assessing whether levels of agreement in the rating of the pre- and post-treatment severity scores are independent, comparing agreement in the two sets of data, and assessing levels of agreement in general.

The distributions of differences in the rating of the severity scores are depicted in Figure 1. There is no evidence of bias in any of the four groups of differences. Combining the 76 differences between the two NSMC raters into one set, we find 54 (71%) show perfect agreement, with the other 22 being split 12:10 (sign test: p=0.8318) with one rater or the other giving the greater severity. Between the 42 differences between the NSMC and DDRC raters, only 35 (48%) showed perfect agreement but there is still no evidence of bias amongst the discordant records, with a 12:10 split once again (sign test: p=0.8318). It is thus apparent that the agreement between these two raters is not as good as that between the two NSMC raters.

A Bland-Altman plot[17] is depicted for information (Figure 1). Due to the constrained space in which the points must lie, and the highly discrete nature of the data, construction of limits of agreement would not be appropriate. There is no evidence of a trend in the inter-rater differences with the magnitude of the severity.

It might be anticipated that the magnitude of the differences would tend to be greater when the ratings are greater, even beyond the tendency for such a trend enforced by the numerical boundaries placed on the possible values. Assuming some sort of Poisson process was taking place, one might anticipate the standard deviations of differences rising as the square root of the severity by analogy with a Poisson process. It is odd then that the greatest inter-rater differences are seen in the post-treatment scores, when severities are typically lower. Speculation on the possible reasons for this is non-profitable for this analysis, and indeed it could be due to chance.

If the agreement for a particular record pre-treatment is independent of agreement for that record post-treatment, then it would be sensible, in some analyses, to combine the pre- and post-treatment data. The pre- and post–treatment inter-rater differences for the two NSMC raters are cross tabulated in Table 2. The same information for the NSMC and DDRC raters is given in Table 3. There is no evidence of an association between pre- and post- inter-rater differences in either Table 2 (Fisher's exact test: p = 0.3893) or Table 3 (Fisher's exact test: p = 0.0870)

Table 2 Cross-tabulating pre- and post-treatment inter-rater differences for the two NSMC raters.

		Inter-rater differences in post-treatment severity						
		-3	-2	-1	0	1	2	4
Inter-rater differences in pre-treatment severity	-2	1			1			
	-1				2		1	
	0		1	2	19	2		1
	1			1	2			
	2				5			

Table 3 Cross-tabulating pre- and post-treatment inter-rater differences for the DDRC and NSMC raters.

		Inter-rater differences in post-treatment severity			
		-2	-1	0	1
Inter-rater differences in pre-treatment severity	-1			5	
	0		3	3	4
	1		1	2	1
	2	1			1

Even if there were a significant association in Table 3, examination of that table reveals that it would not create alarm. There would be cause for concern if there were a strong diagonal presence in the table (i.e. if both the top-left and bottom-right 'white' regions, or *vice versa,* contained many observations). In fact Table 3 shows no observations in the two upper 'white' regions.

Values of Cohen's Kappa for the four groups are given in Table 4. The statistic gives a measure of the level of agreement beyond that which would be expected by chance. While it is difficult to interpret, there are several guidelines as to the interpretation including those published by Altman[18] which suggest that a kappa of greater than 0.6 should be considered good, and greater than 0.8 should be considered very good. While the standard kappa only credits raters for exact agreement, in this situation the weighted kappa is often preferable as a measure. This gives some credit for near misses, thus acknowledging that, for example, one rater giving a score of 16 and the other 17 is not terrible and certainly doesn't deserve to be punished as much as two scores of 25 and 0 (which in the classic kappa it is).

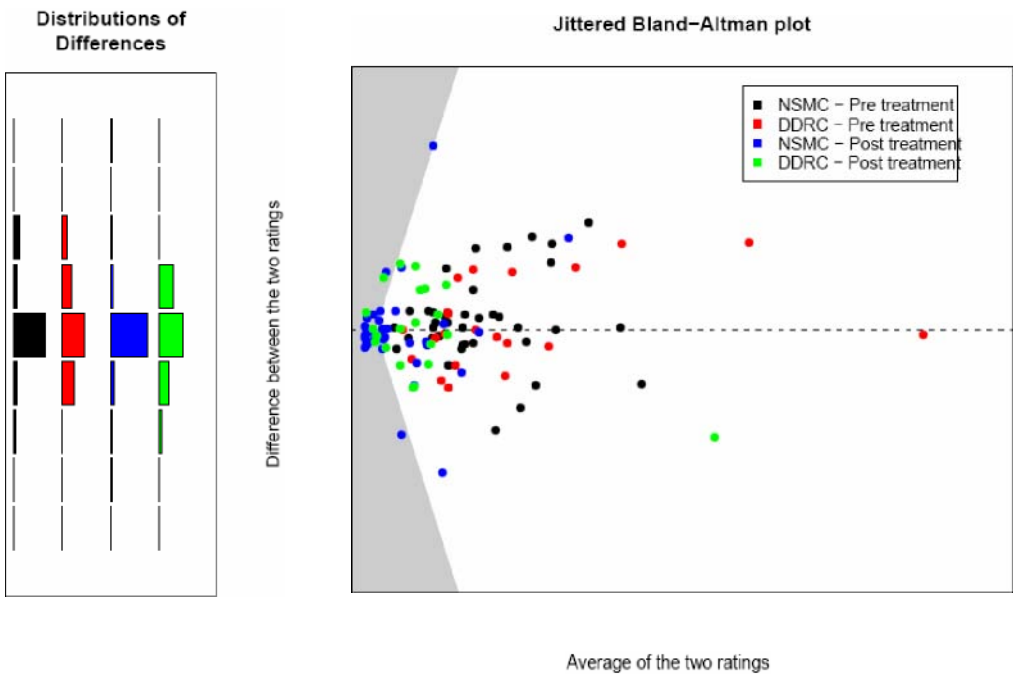


Figure 1 – Broken down by sets of raters (either NSMC vs NSMC or DDRC vs NSMC) and whether the score is pre or post treatment, on the left in the vertical bar charts are depicted the distributions of differences. Also depicted is a jittered Bland-Altman plot, again broken down by the same four groups. This is a plot depicting the difference between two ratings plotted against the average of those two ratings. To avoid the inevitable masking of points by others taking the same values, each point is randomly offset by a small amount; a practice known as jittering. The horizontal line indicating perfect agreement is presented, and the region in which it is numerically impossible to observe differences (due to the bounding of scores at zero) is shaded. Some points may appear to lie in this impossible region due to the jittering.

In Table 4 one can see that the weighted kappa suggests very good agreement between raters in the pre-treatment severities and good agreement post-treatment. It is possible that the post-treatment kappas are being hurt by the fact that so many post-treatment scores are zero, and so the levels of agreement that are expected by chance are going to be very high.

Table 4 The values of kappa for a variety of comparisons.

Data Set	**kappa**	**weighted kappa**
Pre-Treatment, NSMC v NSMC	0.5 87	0.874
Post-Treatment, NSMC v NSMC	0.609	0.709
Pre-Treatment, DDRC v NSMC	0.3 17	0.950
Post-Treatment, DDRC v NSMC	0.264	0.73 8
All, NSMC v NSMC	0.644	0.897
All, DDRC v NSMC	0.3 65	0.955
All	0.55 1	0.933

3.2 DESCRIPTION AND EXPLORATION OF THE DATA

The data are summarized in Table 5. The two data sets are somewhat different in nature, with the DDRC data set being nearly twice the size of the NSMC data set and significantly differing with regard to a number of the covariates. The divers in the DDRC data set are more likely to be female less likely to be professional and are generally older. They are less likely to have a controlled ascent, more likely to be administered oxygen and less likely to be administered IV fluids. Typically they would take longer to receive the hyperbaric oxygen treatment, despite being generally more severe cases. However they are less likely to have residual problems.

Table 5. Summary of the study data

	NSMC	**DDRC**	**Total**	
Number of incidents	**132** (3 8%)	**211** (62%)	**343**	
Categorical covariates. Numbers in each category with percentage in brackets.				**p-value**
Gender M/F	**125**(95)/**7**(5)	**158**(75)/**53**(25)	**283**(83)/**60**(17)	<0.0001
Status Am/Pro	**71**(54)/**61**(46)	**197**(93)/**14**(7)	**268**(78)/**75**(22)	<0.0001
Controlled Ascent	**105**(80)/**27**(20)	**130**(62)/**81**(38)	**235**(69)/**108**(3 1)	0.0005
Y/N	**22**(18)/**102**(82)	**50**(24)/**161**(76)	**72**(21)/**263**(79)	0.2174
Repetitive dive? Y/N	**55**(42)/**77**(58)	**159**(75)/**52**(25)	**214**(62)/**129**(38)	<0.0001
O_2? Y/N	**22**(17)/**110**(83)	**14**(7)/**197**(93)	**36**(10)/**307**(90)	0.0059
IV? Y/N				
Continuous covariates. Median with inter-quartile range in brackets.				
Age (years)	**34** (30 to 40)	**38** (29 to 45)	**36** (30 to 43)	0.022 1
Depth of dive.	**29.5** (22 to 36)	**28** (21 to 37)	**29** (21 to 36)	0.6242
Duration of dive.	**33** (21 to 60)	**33** (26 to 45)	**33** (25 to 47)	0.7582
Time from dive to HBO.	**225** (89 to 805)	**266** (166 to 1086)	**243** (148 to 994)	0.0128
Scores. Median with inter-quartile range in brackets				
Prior to treatment	**3** (2 to 4)	**4** (3 to 6)	**4** (2 to 5)	<0.000 1
Post treatment	**0** (0 to 1)	**1** (0 to 2)	**1** (0 to 2)	<0.000 1
Functional Limitation? Y/N with percentages in brackets				
Prior to treatment	**68**(52)/**63**(48)	**62**(29)/**149**(7 1)	**130**(38)/**212**(62)	<0.000 1
Post treatment	**13**(10)/**118**(90)	**21**(10)/**190**(90)	**34**(10)/**308**(90)	1.0000
Ultimate	**6**(5)/**125**(95)	**5**(2)/**206**(98)	**11**(3)/**331**(97)	0.3458
Residual Score? Y/N				
Ultimate	**41**(33)/**83**(67)	**21**(10)/**190**(90)	**21**(10)/**190**(90)	<0.0001

With so many associations, there is of course some confounding between the covariates, and some of these associations may be explained by additional variables. In particular, the time to HBO from the dive does not appear to be associated with the originating study group once we consider the professional status, whether the dive was a repetition and whether oxygen was administered. Figure 2 shows the associations inherent in the data. Variables are arranged on the page such that, depending on one's perspective, they could not reasonably be thought to depend on variables that lie lower on the page. Indicated via lines are the associations that are apparently significant when a generalized linear model attempts to explain a variable in terms of all 'higher' variables.

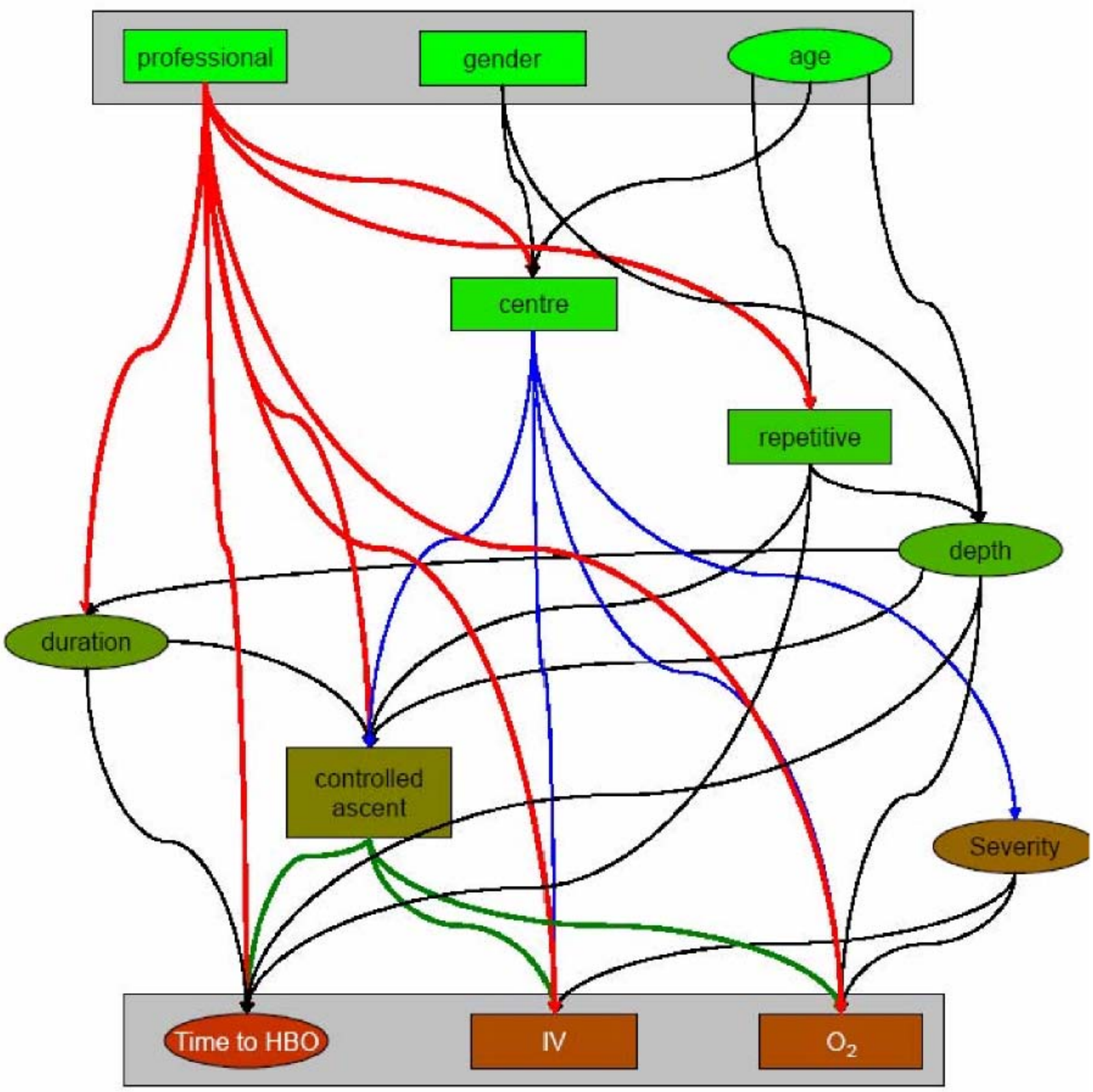


Figure 2: Schematic showing the significant associations apparent in the data. Each variable was modelled in terms of all variables depicted higher or at the same level in the diagram and a connecting line suggests that the variable should be in the final model (as judged by Akaike's Information Criterion (AIC)). Thus the model for the indicator of whether a dive was repetitive is associated in the model with the professional status of the diver and age, but conditional on those, not on the gender, or study centre. Associations with professional status, study centre and controlled ascent have been highlighted in red, blue and green respectively. Binary variables are indicated by rectangles, continuous (or nearly-continuous) variables are indicated by ovals, with the exception of age these were all log-transformed.

Note that the variables depth, duration and initial score are logged in the models. Note also, that the log-transformations and interactions aside, we assume that the linear relationships are valid.

There are a number of positive aspects to these results. It is reassuring that the initial score is not directly associated with the time to treatment, as this would have caused all sorts of problems in terms of bias. Age and gender associate only with variables that are reassuringly ‘high up’ the page. The professional status of the diver is apparently highly influential, with the professionals having quite different behaviours to the amateurs. This is not unreasonable and is no cause for concern as far as the modelling is concerned, but does suggest that it might be prudent to analyse the amateur and professional groups separately as well as conducting the main, combined, analysis.

Whether or not the ascent was controlled seems to have an influence on all of the treatment decisions, and is such one of the crucial variables to consider. The other variable associated with a large number of other variables is the indicator of which medical centre it was at which the diver was treated. The concern might be, despite the apparent good agreement between the study centres reported in the previous section, that this reflects a difference in assessment or record keeping rather than a genuine difference. Thus, again a subgroup analysis might be necessary to ensure the robustness of results.

Another question of interest is one with regard to rates of neurological functional limitation. This seems to fly in the opposite direction to the other measure of prior severity, with functional limitations being more frequent in the NSMC dataset. This suggests that the two datasets have very different profiles of symptoms, or that there is a discrepancy in the manner in which data have been recorded.

3.3 CONFORMATION TO CURRENT GUIDELINES

In this section we look at the various guidelines regarding time to treatment and investigate whether following those guidelines (in the sense that if the guidelines suggest having facilities within 2 hours reach then we class divers who receive treatment within two hours as compliant) is beneficial. We consider three measures of treatment performance. These are the showing of any improvement in post-treatment score compared to pre-treatment score, the presence of any neurological residua after all treatments, and the change from pre-treatment score to post-treatment score.

When using this final measure, we will obviously have to account for the pre-treatment score, as there will be a strong relationship between the two. The indicator of improvement, and indicator of residua have been suggested, as it is hoped that they will avoid such problems.

The current UK Approved Code of Practice (ACOP) for Inshore Diving under the Diving at Work Regulations, 1997 suggests that there may be a benefit to receiving treatment within six hours if diving to a depth of less than ten metres, and within two hours if diving to a depth of between ten and fifty metres.

The levels of compliance to these guidelines, and the levels of response within compliance categories are shown in table 6. Only 59 (17%) of the divers in the study received treatment within the ACOP suggested time, with compliant divers most likely to be male, professional and from the NSMC study. In a multivariate model however, only the professional status is significantly associated with the probability of complying with the guideline time.

Despite the clear association between depth and time-to-treatment explicit in the guidelines, there is no great association apparent in the data (see figure 3). A naïve calculation of Spearman’s rank correlation coefficient reveals it to be significantly non-zero, and negative (suggesting that the deeper the dive the quicker the treatment is indeed received), but very small in magnitude at -0.15. This however appears to be due to an erroneous combination of two subgroups; those for whom it is a repeat dive and those for which it is not. Within these two groups, the correlation coefficients are -0.02 and -0.03 respectively, neither remotely close to being statistically significant (p=0.855 and 0.604 respectively).

It is not possible to answer questions in terms of the proportion of divers who saw a response to the treatment (i.e. whose post score was less than the prior score), because so few divers fail to see a response. The overall rate of failure is approximately 8%, and is consistent across compliance (p=1), gender (p=1), the study centre (p=0.1 13) and professional status (p=0.057, Fisher's exact test in all cases).

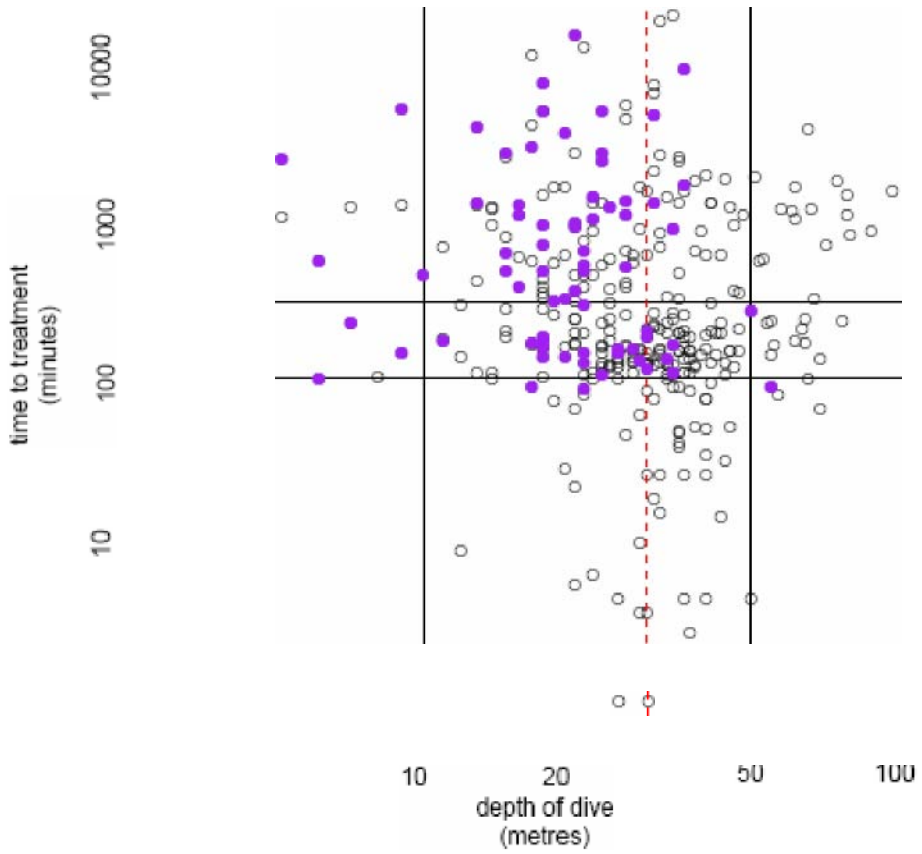


Figure 3 Depicted on logarithmically transformed axes are the observations of depth and time-to-treatment. Lines indicate the boundaries associated with the ACOP. Observations associated with repeat dives are depicted in purple.

Disregarding variables other than score prior to treatment, one can see that there is a trend for the scores of compliant divers to see a greater reduction in score than non-compliant divers (Table 7). The small numbers of compliant divers make it impossible to analyse all of the sub-groups that would be desired, but the trend is apparent amongst the NSMC, male, and professional subgroups.

A rank permutation test of the post-treatment scores[a], conditional on the pre-treatment scores, within the pre-treatment range of 1 to 7 (no scores above 7 have sufficient divers in both categories) shows that the compliant divers do have a significantly greater reduction in score (p<0.00 1). (Within the controlled ascent subgroup, p<0.001, within the NSMC subgroup, p=0.002, and within the male NSMC subgroup, p=0.001.). Just within the 11-50 metre depth subgroup, the reduction is still significant (p<0.001). For details of the methodology of the rank permutation test, see the appendix.

Table 6. Compliance to current UK approved code of practice.

	<2 hours	2-6 hours	>6 hours
<11 metres	Number: 1 RESP 1 (100%) NR 1 (100%	Number: 4 RESP 4 (100%) NR 0 (0%)	Number: 7 RESP 7 (100%) NR 1 (14%)
11-50 metres	Number: 50 RESP 48 (96%) NR 7 (15%)	Number: 132 RESP 12 (91%) NR 23 (18%)	Number: 117 RESP 10 (91%) NR 21 (18%)
>50 metres	Number: 4 RESP 1 (25%) NR 3 (75%)	Number: 11 RESP 10 (91%) NR 3 (27%)	Number: 17 RESP 17 (100% NR 3 (18%)

Table 6 showing the numbers in the data set cross classified by depth of dive and time to first treatment. The cells corresponding to compliance to guidelines are coloured blue. Along with total numbers are reported the number responding to treatment (score post treatment is less than that prior to treatment) and the number exhibiting neurological residua. Percentages may not take the stated number as their denominator if the residual status of some individuals is unrecorded.

Table 7. The effect of hyperbaric treatment in the compliant and non-compliant groups broken down by score prior to treatment.

	Compliant		Non-compliant	
Score Prior to treatment	Number	Score post treatment Median (IQR)	Number	Score post treatment Median (IQR)
1	9	0 (0 to 0)	24	0 (0 to 1)
2	15	0 (0 to 0.5)	59	0 (0 to 1)
3	10	0 (0 to 1)	51	1 (0 to 1)
4	7	0 (0 to 0)	51	1 (0 to 2)
5	4	0 (0 to 0)	33	1 (0 to 2)
6	4	0.5 (0 to 1.25)	20	2 (0.75 to 2.25)
7	5	1 (0 to 3)	12	2 (1 to 3.25)
>7	5	4 (3 to 11)	32	4.5 (1 to 7)

a **The rank permutation test:** In this study we determined if the average ranks of the improvements within the set of compliant divers differ from those within the non-compliant divers. In a second stage of the test we randomly reassign whether the divers were compliant or not (keeping the same total numbers of each). Every time we reassign the compliant status of the divers, we recalculate the statistic. Because the initial severity affects the level of improvement possible, and as such the rank possible, we do this separately within each initial severity value, and then add the differences in average mean rank.

3.4 GENERAL MODELLING IN TERMS OF TIME TO HBO TREATMENT

We will consider a number of models wherein rather than simply using the time-to-treatment to establish a 'compliance to guidelines' statistic we will actually put time-to-treatment (or log-timeto-treatment) into the model.

We begin with a Poisson regression model, one where the post-treatment scores are modelled as being poisson random variables with expected values that we will model in terms of the other variables.

Due to the complexities and instabilities of the space of potential models, we consider only a subset of models, specifically those that are contained within the following format.

$$\begin{aligned} \text{Log}(\text{E}(\mathit{Score}_{post})) = & \text{F}_{score\ prior} + (\text{I}_{NSMC} + \text{I}_{Pro} + \text{I}_{Pro}:\text{I}_{NSMC}) \\ & +(\text{I}_{Male} + \text{age} + \text{logdepth} + \text{logduration}) \\ & +(\text{I}_{C.Ascent} + \text{I}_{IV} + \text{I}_{O2} + \mathit{logTTT} + \mathit{interactions}) \end{aligned}$$

Here we have (on the top line) a factor with levels for each value of the prior score (scores greater than or equal to 8 being combined due to low numbers) and indicators for which study centre the diver was from, whether the diver was professional and we allow an interaction between professional status and study centre since these two variables were so influential on the other covariates.

The second line includes the variables age, log(depth) and log(duration) as well as an indicator for gender. Note that we do not include whether the dive was a repeat or not for two reasons. First it is hard to imagine how this variable could impact on the performance of the treatment, and second there are a number of missing values for this variable that would mean making the data set smaller were we to use it.

The third line includes the treatments, the log-time-to-treatment (logTTT) and indicators for IV fluids and normobaric oxygen, and an indicator for controlled ascent that we earlier saw to be associated with the three treatments. First order interactions between these four variables are also considered as they are the most important in the model from the point of view of the questions we are asking.

The final model we reach (by AIC) is as follows:

$$\begin{aligned} \text{Log}(\text{E}(\mathit{Score}_{post})) = & \text{F}_{score\ prior} + \text{I}_{NSMC} + (\text{I}_{Male} + \mathit{age} + \mathit{logdepth}) \\ & +(\text{I}_{IV} + \text{I}_{O2} + \mathit{logTTT} + \text{I}_{O2}: \mathit{logTTT}) \end{aligned}$$

So the log(duration) variable and professional status and controlled ascent indicators have fallen out of the model, and the only interaction included is that between the normobaric oxygen and time to treatment. The details of the fitted coefficients are given in Table 8.

Note that the effects of the prior score are monotonically increasing, which is reassuring, and that being in the NSMC database, being young or being male reduces the score post treatment. Diving deeper or taking a long time to receive treatment is associated with a higher score post-treatment (so a lesser effect), as is receiving either intravenous fluids or normobaric oxygen. However, the interaction between normobaric oxygen and time to treatment negates this somewhat. Despite gender not apparently being required by the Wald test (see the p-value in table 8), the AIC measure suggests that it should be retained in the model. There would be little harm in erroneously retaining it in this model, so we do so.

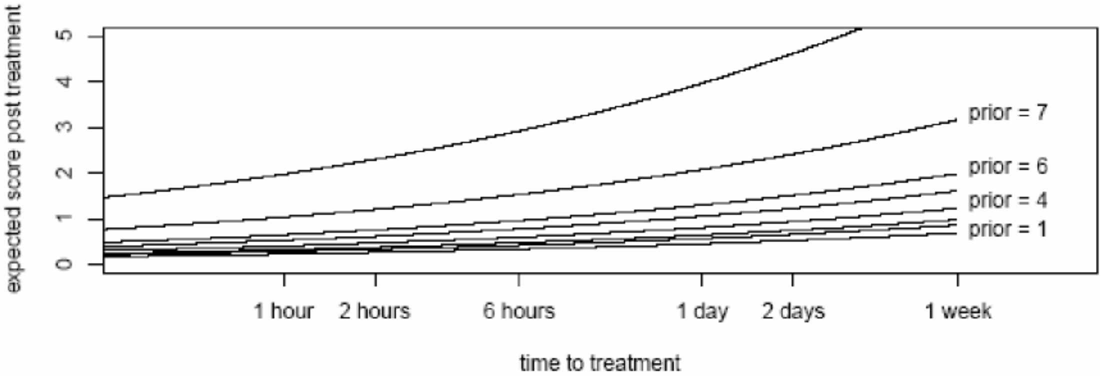
Table 8 Summary of the Poisson regression model.

	coefficient	standard error	p-value
Intercept	-3.88	0.57	<0.01
Prior Score = 2	0.23	0.33	0.49
Prior Score = 3	0.36	0.33	0.27
Prior Score = 4	0.59	0.32	0.07
Prior Score = 5	0.86	0.33	0.01
Prior Score = 6	1.07	0.34	<0.01
Prior Score = 7	1.55	0.33	<0.01
Prior Score > 7	2.19	0.31	<0.01
NSMC	-0.48	0.14	<0.01
Male	-0.21	0.13	0.12
age(-36.5)	0.01	0.01	0.02
logdepth	0.64	0.09	<0.01
IV	0.50	0.13	<0.01
O_2	1.34	0.54	0.01
logTTT	0.22	0.05	<0.01
O_2:logTTT	-0.25	0.08	<0.01

We display the results from fitting the model to various subgroups in Table 9. Due to the small numbers in some of the subgroups, the prior-score factor coefficients were not estimated in these models, but rather taken from the overall model. Note that there is considerable consistency amongst the subgroups, with only the professional subgroup looking out of place, and this may be due to the small size of the professional group.

Table 9 Robustness of the Poisson Regression Model

	All	DDRC	NSMC	CA	UA	FL	No FL	Pro	Am	O_2	No O_2
Group size	341	209	132	234	107	130	210	75	266	212	129
TTT	0.22	0.16	0.28	0.23	0.44	0.21	0.22	0.41	0.09	-	0.22
IV	0.50	0.60	0.38	0.36	0.65	0.42	0.96	1.81	0.51	0.03	0.13
O_2	1.34	1.26	0.41	0.71	3.11	0.97	1.59	-	0.57	0.56	
O_2:TTT	-	-0.25	-0.11	-	-	-	-	0.62	-		
log(depth)	0.25	0.66	0.48	0.15	0.52	0.17	0.31	0.10	0.15		0.18
NSMC	0.64			0.38	1.14	0.76	0.36	0.55	0.55	0.77	-
Male	-	-0.23	0.36	-	-	-	-	-	-	-	0.34
Age	0.48	0.01	-0.10	0.31	0.74	0.64	0.13	0.02	0.56	0.54	-
	-			-	-	-	-	-	-	-	0.07
	0.20			0.18	0.19	0.16	0.22	0.05	0.19	0.26	0.01
	-			0.03	-	0.01	0.02	0.05	-	0.01	
	0.01				0.01				0.14		



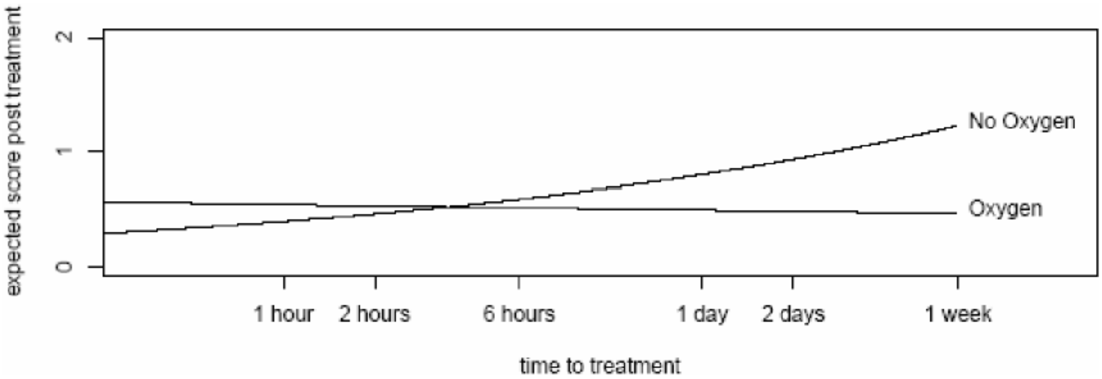


Figure 4

Above: Illustrating the effect on the fitted curves of varying the time to treatment and the severity score prior to treatment. Curves are presented corresponding to prior severity scores of 1, 2, 3, 4, 5, 6, 7 and >7 for divers in the NSMC database who are male, dive to an average depth, are of average age and receive neither intravenous fluids nor normobaric oxygen.

Below: Illustrating the effect on the fitted curves of varying the time to treatment and administering normobaric oxygen for a diver with a prior severity score of 4 (all other details as above).

One presumes that rather than actually negating the effects of the HBO treatment, the administration of intravenous fluids or normobaric oxygen are indicative of an increased level of severity on the part of recipients that is not picked up in the usual score. There is considerable evidence here that the sooner one receives treatment, the better the outcome will be.

Note also that the interaction between normobaric oxygen and the log-time-to-treatment will almost exactly cancel out the log-time-to-treatment coefficient amongst divers that received normobaric oxygen. This is further highlighted by the lack of a substantial log-time-to-treatment coefficient in the O_2 subgroup. There could be a number of interpretations of this result, between which we cannot distinguish due to the design of the study. These include the possibility that normobaric oxygen is being given to more severe cases who will not do particularly well, no matter how quickly the HBO treatment is given. A more exciting interpretation might be that normobaric oxygen could protect divers from the costs associated with delayed administration of HBO treatment. Which the reason will need to be addressed by informed discussion, or future prospective, and more focussed, studies.

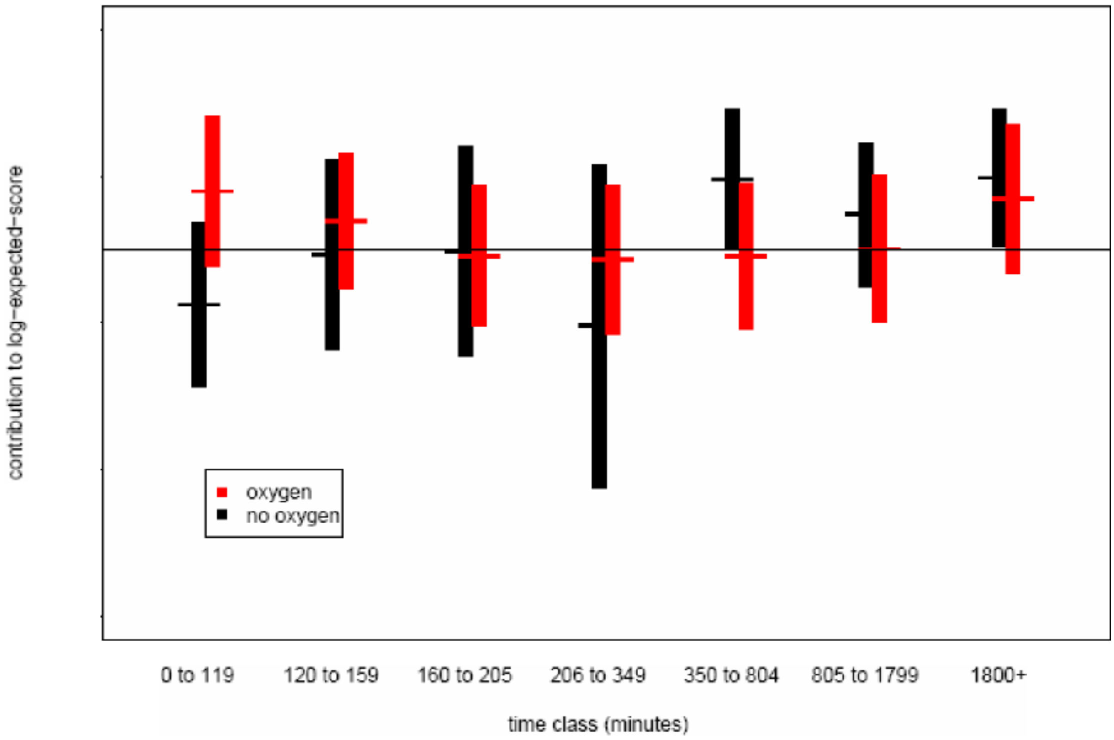


Figure 5 Depicted are 95% confidence intervals for the contribution to the expected log-score associated with each of the seven time classes for divers who received or did not receive normobaric oxygen. A horizontal line at y=-3 is presented to aid assessment of trends.

To investigate whether there might be a threshold effect in the model, we change from a continuous measure of time to a multi-factor representation. It is crucial that in each time class we observe both normobaric oxygen receivers and non-receivers, and so we may not be able to choose class boundaries to be round numbers. The results are shown in figure 5. As anticipated there is no noticeable trend amongst the divers who received normobaric oxygen, or if there is it is an inexplicable quadratic trend. Amongst those who did not receive this treatment, we can see that beyond 350 minutes, there is an increase, but whether this is a step change or a gradual progression cannot be assessed from these data (nor easily interpreted if it could).

4. DISCUSSION

This study of divers who developed neurological DCI provides medical evidence that receiving HBO treatment sooner is associated with greater effectiveness and a better outcome. The study involved two hyperbaric units in the United Kingdom (The McIver Unit in Great Yarmouth and the Diving Diseases and Research Unit in Plymouth). 343 cases of neurological DCI met the inclusion criteria of the study. There was a significant variance of the profiles of the datasets of DDRC and NSMC in terms of gender, professional status, rapid uncontrolled ascent from depth, administration of normobaric oxygen and intravenous fluids, age, the time taken to receive HBO treatment and the severity of initial symptoms. This means in a sense that the outcome of the study could be generalized but also that we need to look at subgroups in the study to ensure robustness.

The questionnaire used in this study demonstrated a good inter-rater agreement (a good reliability) between different raters of the respective Units (NSMC and DDRC). This was an indication that the two datasets could be merged. This also indicates that the questionnaire could be used in similar studies where change in severity of neurological decompression illness needs to be evaluated or reported over time; alternatively the questionnaire could be used to communicate the severity of neurological decompression illness to a treatment facility or to a diving physician from a remote diving site in order to obtain medical advice. A ratio scale, such as the one used in this study, has preference over nominal, ordinal or interval scales as a ratio scale could describe the numerous manifestations of DCI as a single numerical and as the other scales leads to loss of information. [19] It has to be mentioned that no numerical score is likely to be able to capture the full effect of biological response. Observed discrepancies between a diver's clinical state and the numerical score as allocated by questionnaire were in vestibular DCI cases and cases where a diver lost consciousness.

General statistical modelling showed that a shorter time to hyperbaric oxygen treatment was associated with a better outcome in divers with neurological decompression illness. Whether the association with time to treatment is continuous or a step function cannot be determined statistically. The Poisson regression model indeed show that time to HBO treatment is robust in these subgroups whilst other variables such as gender and age are not (Table 9).

We also examined the current UK ACOP[2] under the Diving at Work Regulations 1997, which gives time limits in which a chamber should be available for a specific dive (referring to diving depth and decompression time) should a diver develop DCI. The data show that the vast majority of divers do not receive treatment within the guideline time and that divers are more likely to meet the guideline time if they are professional. There are very few divers who do not see an improvement of DCI and there was little variation in rates of neurological residua between the different groups. ~A rank permutation test showed that HBO treatment has greater effect on those who first receive it within the guideline time, as laid down in the ACOP. The divers who receive treatments within the recommended guideline times are in the minority, although professional divers are more likely to comply. A non-parametric test based on the ranks of the actual score post-treatment while conditioning on the scores pre-treatment does show that those who complied with guidelines saw better responses to treatment than those who didn't.

When planning to undertake diving activity, a diving contractor/ employer should not only take time to treatment into account, but also other variables such as whether decompression diving is undertaken, free or buoyant ascent training is being conducted; diving will involve trainees in diving activities where the trainees' inexperience can predispose them to uncontrolled ascents or added risks; diving depth and if diving exceeds the depth/ time limits laid down; the nature of the environment or work to be conducted creates risk of extended bottom time, entrapment or uncontrolled ascent; diving will occur in situations where the surface diving environment could change rapidly over the course of the dive (where surface support, controlled ascent or in water stops may be compromised); or where the nature of plant and equipment used during the dive or on the dive site can be reasonably foreseen to result in a substantial increase in risk.

Research[20] of patient behaviour on why patients with chest pain delay, or do not call, 911 suggests that the lack of self-efficacy beliefs (ie, the belief that one has the ability to perform a certain behaviour) may be a more important factor in helping to get people to act quickly than knowledge of the signs and symptoms of ischaemic chest pain. The same principle could be extrapolated to divers needing HBO for DCI symptoms. Planning on what action to take when a diver develops suspicious symptoms and how to respond to these symptoms, especially if the symptoms are ambiguous, may minimize lengthy discussions that precede decision making no what to do when there is no action plan in place. Aspects may include mode of transport, accompanying persons, administration of normobaric oxygen and to which hyperbaric chamber a patient should go. Some of the reasons for delay in seeking hyperbaric treatment early if there are suspicious DCI symptoms after a dive could be: confusion or uncertainty how to interpret the symptoms; perceived barriers to seeking care quickly (e.g. cost, inconveniencing the diving buddies, embarrassment); divers may think that the symptoms would go away; the symptoms were not severe enough; the diver thought that the symptoms were caused by another illness/ reason; or if the diver thought self transport would be quicker. Awell laid out plan by a diving contractor/ employer on what to do and when, should a diver develop suspicious DCI symptoms after a dive, will help to ensure prompt HBO treatment.

Those who received IV fluids in this study did not improve as well as those who did not. This suggests that the use of IV fluids is a ‘flag’ for more serious cases. There is therefore the possibility that intravenous fluid (IV) administration could be seen as an “identifier” for severe cases in the study as the hyperbaric duty doctor initiates IV fluid administration in clinically severe cases. Previous research did show that dehydrated divers reflected by a high hematocrit value had a worse outcome.[21] There is the possibility that more seriously affected DCI cases have difficulty in replacing lost fluids through oral intake before IV fluids are administered, thereby experiencing an episode of fluid depletion where the serum osmolality (or hematocrit) could increase. Administration of hypotonic fluids could also worsen outcome by increasing areas of oedema in the nervous system.

The analysis shows that receiving normobaric oxygen tends to protect against a delay in hyperbaric treatment. Previous research has shown the benefits of receiving normobaric oxygen in DCI cases. HBO is the definitive treatment in divers with DCI; normobaric oxygen should never be regarded as a substitute for HBO in divers with DCI and should not be a reason to delay HBO. There are several other factors regarding normobaric oxygen administration that are important and not mentioned in this study due to insufficient detail in the records: These are how soon normobaric oxygen was administered after the incident dive, the percentage of oxygen administered and the duration of administration. These details about normobaric oxygen administration could be a subject of future study.

Possible sources of bias could be assessor bias as the investigators were not blinded to the time to HBO therapy variable. The good interobserver correlation obtained in both before and after scores indicates that assessor bias is not significant. Due to the neurological scoring system used, this study is not biased towards spinal cord disease as previous studies.

As this is an observational study, detection of an association (time to HBO and response of neurological DCI cases to HBO treatment) does not imply a causal relationship. It will however be difficult and not likely to be ethically sound to use a randomized control trial to investigate the influence of time to HBO in neurological DCI cases. The data were also sparse in a number of key areas, such as divers diving less than 10m, which will prevent some questions being addressed.

It is reassuring that the initial score is not directly associated with the time to treatment in the analysis, as this would have caused all sorts of problems in terms of bias: For example, a diver with severe DCI is rushed to the hyperbaric unit for treatment whilst a diver with mild symptoms may delay in seeking HBO treatment. Such diver behaviour is therefore unlikely to be a source of bias.

5. CONCLUSIONS

1. There is consensus amongst diving doctors that there is no substitute of quality supportive medical care in a seriously injured diver. This care is generally delivered in a hospital setting by medical expertise and includes invasive procedures such as central venous lines, inotropic support, etc.

2. This study provides medical evidence which supports the fact that the sooner an injured diver receives HBO, the better the outcome for the diver; prompt treatment could therefore limit disability in divers associated with DCI and result in prompt resolution of symptoms. There is a suggestion that, in order to receive the optimal effect of HBO, a diver with DCI should receive HBO treatment within 6 hours after surfacing from the incident dive.

3. Concerning hyperbaric chamber availability, this study provides evidence that supports the current ACOP for inland/ inshore diving regarding times in which divers with DCI should receive HBO.

4. There is evidence that normobaric oxygen protects divers against progression of neurological DCI symptoms, and in this study there is evidence to suggest that normobaric oxygen may even compensate for delays in administering HBO. This finding may need to be explored in further studies.

5. The questionnaire used in this study to assess the degree and severity of neurological DCI is simple and reliable so that it could be administered to assess the severity of neurological DCI in a diver by a non-medical person in a remote location. The assessment could then be discussed by telephone with a medical person who in turn could advise on treatment of an injured diver. This questionnaire could also be considered to form part of a reporting system of neurological DCI cases to the HSE.

6. Factors identified in this study such as time to HBO and normobaric oxygen administration to a diver could be used by medical professionals to advise on the degree of expected resolution of symptoms and signs in an injured diver.

6. RECOMMENDATIONS

1. Time to hyperbaric treatment needs to be taken into consideration when planning a diving operation for work purposes. This study provides evidence that supports the time limits regarding chamber availability as laid down in the current ACOP[2] for inland/ inshore diving under the Diving at Work Regulations, 1997.

2. Normobaric oxygen should be immediately available in all diving operations to be used in the case of an emergency, preferably with a reservoir bag or a demand system to achieve the highest possible oxygen concentration.

3. A diving contractor/ employer may need to obtain the emergency advice of a diving physician, who has the medical responsibility for the diving operation, to weigh the benefits of prompt HBO up against transferring an injured diver to a specialized unit for supportive treatment and HBO. A nominated diving physician who takes responsibility of decisions regarding the medical management of an injured diver such as the appropriateness of transferring a diver to a specialized centre for treatment may form part of the diving project plan. The author's view is that diving physician is in the best position to assess the clinical state of the diver to make a decision on whether the injured diver should be transferred to a specialized medical centre for treatment, or if the diver should have prompt HBO treatment at the closest hyperbaric chamber.

4. The questionnaire used in this study could form the basis of the development of a clinical diving incident reporting system to the HSE. Such a system could be undertaken by doctors with medical responsibility for diving operations. Such a reporting system may help the HSE to identify diving operations/ practices that has a high incidence of DCI (and a poor response to HBO treatment) which in turn could be used to initiate preventative action. The time taken to HBO treatment could be included into each suggested incident report. The recommendation is that the HSE establishes a Working Party to design a specific DCI incident reporting format.

5. Knowledge of symptoms and signs of the illness in divers are important. However, previous research has shown that this knowledge is not sufficient to ensure change in patient behaviour so that patients seek specific treatment earlier rather than late. A well laid out *time to treatment action plan (TTT action plan)* on what to do when a diver develops suspicious symptoms will be more effective in ensuring prompt HBO treatment in divers. The recommendation is that a *TTT action plan* should form part of a diving project plan.

6. Further study is necessary to identify individuals, at employment medical examination, who are susceptible to developing DCI after diving activity.

7. REFERENCES

1. Approved Code of Practice for Commercial Diving Projects Offshore (1998) under the Diving at Work Regulations 1997. HSE Books: 27

2. Approved Code of Practice for Commercial Diving Projects for Inland/ Inshore Diving (1998) under the Diving at Work Regulations 1997. HSE Books: 21

3. A code of good working practice for the operation and staffing of hyperbaric chambers for therapeutic purposes. 1994. The Faculty of Occupational Medicine, Royal College of Physicians, London.

4. Rivera JC. Decompression sickness among divers: an analysis of 935 cases. Milit Med 1964; 129: 134-334

5. Kizer KW. Delayed treatment of dysbarism. A retrospective review of 50 cases. JAMA 1982; 247: 2555-2558

6. Van Hulst RA. Analysis of ten year diving casualties 1979-1989, Diving Medical Centre, The Netherlands. Proceedings of the XVI Annual Scientific Meeting of the European Underwater and Baromedical Society: EUBS 90, Amsterdam, Netherlands: 28 1-287

7. Rudge FW, Shafer MR, The effect of delay on treatment outcome in altitude-induced decompression sickness. Aviat Space Environ Med 1991; 62:687-90

8. Vann RD, Denoble P, Emmerman MN, Corson KS. Flying after diving and decompression sickness. Aviat Space Environ Med 1993; 4: 810-807

9. Ball R. Effect of severity, time to recompression with oxygen, and re-treatment on outcome of forty-nine cases of spinal cord decompression sickness. Undersea Hyperbaric Med 1993; 20(2): 133-45

10. Dick APK, Massey EW. Neurological presentation of decompression sickness and air embolism in sport divers. Neurology 1985; 35: 667-671

11. Boussuges et al. Neurologic decompression illness: A gravity score. Undersea Hyperbaric Med 1996; 23(3): 151-5

12. Desola J, et al. Outcome of dysbaric disorders is not related to delay in treatment. Preliminary results of a multivariate analysis of 466 cases following a prospective study. Proceedings of the XXIII Annual Scientific Meeting of the European Underwater and Baromedical Society: EUBS 97, Bled, Slovenia

13. Ross JAS. Clinical audit and outcome measures in the treatment of decompression illness in Scotland. Department of Environmental and Occupational Medicine. University of Aberdeen Medical School. April 2000

14. Verdier-Taillefer MH, Roullet E et al. Validation of self-reported neurological disability in multiple sclerosis. Int J Epidemiology. 1994; 23: 148-154

15. Freiberger JJ, Denoble PJ, Pieper CF, Uguccioni DM, Pollock NW, Vann RD. The relative risk of decompression sickness during and after air travel following diving. Aviat Space Environ Med 2002; 73: 980-4

16. R Development Core Team (2006). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org.

17. Bland JM, Altman DG (1986), Statistical Methods for assessing agreement between two methods of clinical measurement. Lancet, 1(8476): 307-10

18. Altman DG (1990), Practical Statistics for Medical Research, Chapman & Hall/CRC

19. Abramson JH. Survey Methods in Community Medicine. 2nd Ed Churchill Livingstone, 1979: 84-92

20. Meischke H, Ho MT, Eisenberg MS, Schaeffer SM, Larsen MP. Reasons patients with chest pain delay or do not call 911. Annals of Emergency Medicine 1995; 25(2): 193-197

21. Boussuges A, Blanc P, Molenat F, Bergmann E, Sainty JM. Haemoconcentration in neurological decompression illness. J Sports Med 1996, 17(5): 35 1-5

APPENDIX 1.

Questionnaire administered by the investigators used in this study[14].

Reference 14: Verdier-Taillefer MH, Roullet E et al. Validation of self-reported neurological disability in multiple sclerosis. Int J Epidemiology. 1994; 23: 148-154

What is the level of intensity of each problem listed below? **Intensi**

Symptoms and signs.	**None**	**y Mild (does not interfere with**	**Moderate/ severe (does interfere with activity)**
1 Weakness of right arm	0	1	2
2 Weakness of left arm	0	1	2
3 Weakness of right leg	0	1	2
4 Weakness of left leg	0	1	2
5 Leg stiffness	0	1	2
6 Tremor	0	1	2
7 Clumsiness of arms	0	1	2
8 Loss of balance	0	1	2
9 Double vision	0	1	2
10 Difficulty in speaking and/ or swallowing	0	1	2
11 Uncontrolled urinary urgency	0	1	2
12 Difficulty in urination, incomplete micturition or bladder emptying	0	1	2
13 Constipation	0	1	2
14 Loss of control of bladder	0	1	2
15 Loss of control of bowel	0	1	2
16 Difficulty in feeling contact	0	1	2
17 Difficulty in feeling heat	0	1	2
18 Difficulty in feeling pain	0	1	2
19 Pain or burning sensation in any part of the body (accompanied by other neurological symptoms or signs)	0	1	2
20 Bizarre feelings (paraesthesiae or constrictive feeling) in any part of the body	0	1	2
21 Difficulty with memory	0	1	2
22 Difficulty with calculation	0	1	2
23 Difficulty with reasoning or thinking	0	1	2
	>7/10 (reading possible)	6/10 to 4/10; recognition possible	3/10 to 2/10; distinction of forms or worse
24 level of vision of right eye	0	1	2
25 Level of vision of left eye	0	1	2

Functional systems are evaluated as follows: Pyramidal: Sum of item 1-5 Cerebellar: Sum of item 6-8
Brainstem: Sum of item 9-10
Bladder and bowel: Sum of item 11-15
Sensorial: Sum of item 16-20
Mental: Sum of item 21-23
Visual: Sum of item 24-25

Published by the Health and Safety Executive 05/07

Health and Safety Executive

Time to treatment for decompression illness

Hyperbaric oxygen treatment (HBO) is the standard and definitive treatment for divers with decompression illness (DCI). There is conflicting evidence in the medical literature on whether DCI is more responsive to early rather than late treatment with hyperbaric oxygen (HBO). The main aim of this study is to investigate the influence of time to treatment with HBO in divers with neurological DCI.

Here we show that early HBO treatment in divers with neurological DCI is robustly associated with a better outcome. There is a suggestion in this study that divers with DCI are less responsive if HBO treatment is delayed for 350 minutes or more (or approximately six hours) after surfacing from the incident dive. An interesting observation in this study is that if normobaric oxygen is administered before HBO, it tends to protect divers against delay in treatment with HBO. An additional analysis provides medical evidence that time limits for HBO as specified in the current ACOP[1] should remain in place.

This study recommends that a time to treatment action plan (TTT action plan), which specifies what to do when a diver develops suspicious DCI symptoms, will help to ensure that divers have prompt HBO treatment. Divers with serious DCI should be given the appropriate level of medical care in a hospital setting.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

[1] ACOP: Approved Code of Practice for Commercial Diving Projects for Inland/Inshore Diving (1998) under the Diving at Work Regulations 1997

RR550

www.hse.gov.uk