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Evaluation of Doppler monitoring for the control of hyperbaric exposure in tunnelling

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Evaluation of Doppler monitoring for the control of hyperbaric exposure in tunnelling

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Decompression illness occurs either as symptoms arising soon after the hyperbaric exposure (decompression sickness (DCS)) or as chronic effects (such as dysbaric osteonecrosis) that do not become apparent until many years later. After hyperbaric exposures, the return to atmospheric pressure is routinely achieved by gradual decompression following set tables, and in modern times with breathing of oxygen (eg oxygenated Blackpool Table). The tables are designed to allow for the hyperbaric exposure pressure and duration, but the health risks are not fully controlled for all exposure conditions. Therefore there is a need to be able to monitor and improve the effectiveness of decompression procedures under routine operational conditions in compressed air tunnelling. Doppler monitoring of gas bubbles in the venous blood might fulfil that need.

This potential application of Doppler monitoring was evaluated by assessing the theoretical and practical issues in using Doppler, analysing the published studies that compare Doppler scores to related incidence of DCS, quantifying the relationship of Doppler scores to predicted level of gas in venous blood, and assessing the practical issues and experience of Doppler monitoring in tunnelling work. Doppler scores correlate with risk of DCS, and DCS has been associated with long term health effects. Data from diving trials and hypobaric exposure trials indicate that the correlation of Doppler grades with risk of DCS is not the same for all situations, which may be because the monitored bubbles are on their way out of the body and therefore are unlikely to be the ones causing the DCS.

Only a small part of the available data (relating to Doppler scores) were from compressed air work or compressed air work simulations. The variability of Doppler results between individuals and between small groups means that Doppler scores have limitations in routine operational use. However, they are indicative of relative risk. The role of Doppler is likely to be limited for routine operational use at the current level of knowledge, but we make recommendations on what would be needed to make Doppler monitoring suitable for routine use in compressed air work in the UK.

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SUMMARY

Introduction

Despite progress in reducing the risk of decompression illness in compressed air workers, there remains a concern about the health risks incurred under current decompression procedures. These risks include acute decompression sickness (DCS) and longer term health effects such as dysbaric osteoenecrosis.

The traditional method of assessing the relative safety of hyperbaric working conditions has been in terms of the incidence of acute decompression sickness. However, there are inherent disadvantages in relying on reporting of subjective symptoms that may appear minor even though they could be indicative of serious health risk. Furthermore, modern tunnelling with tunnel boring machines involves much fewer man-shifts of hyperbaric exposure than older methods of tunnelling. So the future data on decompression sickness (DCS) in modern tunnelling projects may be too limited to provide a reliable basis for assessing the health risk of hyperbaric exposure.

Doppler monitoring of gas bubbles in the venous blood is a potential tool for obtaining an indication of decompression stress in operational compressed air work. However, the bubbles detected are in the blood and are on their way out of the body, and therefore they are probably not the bubbles that cause most health effects. The occurrence and time course of those bubbles are probably not identical, but may be similar enough for the monitored bubbles to be a useful surrogate for the bubbles that are believed to be the cause of most DCS and other health effects.

Therefore, this study was undertaken to assess the potential for using Doppler monitoring to help regulate decompression stress in operational compressed air work. The study aims to describe the nature of Doppler measurements, review the evidence on the association between Doppler scores and health effects, examine the relationship between Doppler scores and theoretical levels of decompression stress, describe practical experience of using Doppler monitoring in compressed air tunnelling operations, and assess the implications for future use under typical operational conditions in the compressed air industry.

One of the key characteristics of Doppler measurements is the variability in the results between individuals exposed to similar compression/decompression regimes, and the consequent variability in average data from small groups such as now form a compressed air team for a given shift. Typically, perhaps half a dozen men are exposed at a given time. The questions addressed by this study include whether the Doppler scores can be used to asses the adequacy of a decompression procedure in operational practice or if Doppler scores for the individual or for the group on the shift could be used to identify those who could or should be offered prophylactic recompression (i.e. to identify where the risk of DCS should be deemed unacceptably high following a single routine exposure and decompression).

The available data relate only the acute decompression effects, and not the longer term health effects, to Doppler scores. Therefore the relationship between Doppler scores and acute DCS, as indicated by published studies is examined and summarised. Protection against acute DCS may well help to protect against the recognised long term health effects but there are no data to test the supposition.

The subject is complex, and this summary is extensive. Conclusions and recommendations are at the end of the summary.

Background

UK data on incidence of acute decompression sickness indicates that for decompression from certain combinations of pressure and duration (e.g. over 2 bar for more than 4 hours), the risks of acute decompression sickness have been of the order of 1 to 2% for air-only decompressions during recent years. Decompression with oxygen breathing has been shown in theory and in laboratory trials to reduce decompression stress and therefore its operational use since September 2001should have reduced the risk of acute DCS. However, at the time of writing this report, there is only very limited experience of tunnelling with oxygen decompression in the UK.

An HSE Workshop on decompression stress (Simpson, 1999) concluded that "*Monitoring of venous gas embolisms* (i.e. gas bubbles in the veins) *is an appropriate indicator by which to measure the safety of a decompression procedure. Definition of a 'safe' level of bubbling remains to be defined in relation to health effects.*" We review the published data on acute DCS in relation to Doppler scores in an attempt to define a 'safe' level in respect to that health effect.

An important part of the background is that individual susceptibility is recognised as being a major factor in relation to acute DCS. Approximately 4% of the compressed air work force carry the burden of about 50% of the recorded DCS. If high Doppler scores were found to be indicative of susceptibility, then that could help the Contract Medical Adviser to protect such individuals, and to reduce (potentially, greatly reduce) the overall morbidity associated with compressed air work.

Methods

Key papers on the use of Doppler monitoring were selected for review. The review assessed the factors that may affect the Doppler data and their interpretation, including the variations in the recording technique, the operator subjectivity in interpretation of recorded signals, the relationships between Doppler grade and risk of DCS, the sensitivity and specificity of the Doppler measurement, and the reliability of using Doppler grades to predict risk of DCS in individuals and in groups.

Largely unpublished data from laboratory trials with Doppler monitoring were used as a basis for relating Doppler scores to a theoretical index of decompression stress calculated from a mathematical model of the process of bubble formation during decompression. The model describes gas being absorbed and desorbed from the organs of the body in accord with physiology and the physics of absorption of gas into liquid and body tissue, and it produces a prediction of the gas (as bubbles) in central venous blood which can be compared with the level of bubbles indicated by Doppler scores.

Finally, recent practical experience in using Doppler monitoring under typical operational conditions was examined to determine the lessons for future use.

Review of Published information

The principles

The review describes the basic principles of formation of gas bubbles during decompression. Compression produces increased concentration of dissolved gas in the blood and in tissue. The duration of time spent at pressure and the time course of decompression determines the occurrence of supersaturation, and hence formation of bubbles. This process is not directly observable or measurable, but can be theoretically predicted or modelled. For example, Lambertsen *et al* (1997) used a computed theoretical Bubble Growth Index (BGI) as a single stress index for each exposure (compression /decompression) profile. Flook uses a physiologically based model to predict gas as bubbles in the body. These models calculate an index of the exposure profile, which relates to what is expected to happen in the human body but they do not describe differences between individuals and therefore do not address differences between individuals in propensity to bubbling or susceptibility to DCS. Nor do the models address the differences within individuals from day to day.

Venous gas embolisms (VGE) and decompression sickness (DCS) are both observable effects of decompression stress. Lambertsen *et al* (1997) point out that they may well be correlated, but the detectable venous gas embolisms probably do not cause the DCS, which is more likely to be the result of gas embolisms elsewhere in the body. Indeed they frame the question as "*whether the degree and time course of monitored VGE can themselves provide a practically useful basis for predicting incidence and degree of the pathologic processes induced in tissues other than blood*".

In the conclusions of their report, Lambertsen *et al* (1997) judged, *inter alia,* that:

- Within the data set examined, Doppler grade of VGE was related to a theoretical index of decompression stress, the Bubble Gas Index (BGI);
- Quantitative "*average* correlation" of VGE severity and DCS incidence, as two different expressions of decompression, could be derived by linking each to the same theoretical index of decompression stress (such as their BGI).

Since Lambertsen *et al* (1997) also concluded, "on conceptual grounds", that "quantitative correlations of increasing decompression stress," (*expressed by a theoretical index*) "incidence of severe VGE, and incidence of identified decompression sickness were inevitable and should be derivable", they surmised that the question is perhaps not whether each effect is correlated to the theoretical index, but whether the relationships (VGE to theoretical index, DCS to index) will be sufficiently coincident for monitoring of VGE to be practically useful for controlling hyperbaric exposure.

Theoretical considerations of the recording technique

The Doppler method relies on transmitting high frequency sound (ultra sound) waves from a piezoelectric crystal (the transducer) into the body and receiving the echoes. Where the sound wave encounters boundaries between materials that have different acoustic impedance (defined as the product of density and sound velocity), then some of the energy is reflected back. From theory, 99.9% of the incident energy will be reflected or scattered by an air bubble.

The Doppler effect is the shift in frequency that occurs when sound is emitted or reflected from a moving object. Therefore the Doppler technique detects moving bubbles in the blood stream, not the stationary bubbles. The frequency shift is dependent on both blood speed and the angle between incident beam and blood flow, so the reflected signal shows a wide range of shift.

The choice of frequency affects the suitability of the probe and the sensitivity. Technical advances may influence comparability of modern and early results.

example, at 4 μl/ml of gas predicted in central venous blood, the expected percentage of scores at or above Doppler Grade III is 20%.

The data set included 752 exposures with recorded Doppler grades, plus 3 exposures where DCS occurred before a Doppler score was recorded. There were 20 cases of DCS in the data set. All the DCS cases occurred in groups with at least one individual with a Grade III score. Across the data set as a whole, the % incidence of DCS increased with recorded maximum Doppler grade, from 0.5% DCS at Grade 0, 1.3% for Grade I, 2.0% for Grade II, 6.6% for Grade III, and 10% for Grade IV.

When the exposures were divided into 5 subsets each of about 150 man-exposures, with predicted gas in blood rising from subset 1 to subset 5, the results showed a slightly variable rate of DCS for each subset but no systematic increase in DCS incidence with predicted gas. The dependence of DCS incidence on Doppler scores therefore appeared to be more than just a reflection of increasing theoretical stress. Perhaps the Doppler scores reflected individual susceptibility and/or ancillary factors that affect the risk. This suggests that Doppler scores do provide information that is additional to that from the theoretical prediction of gas in blood based on the exposure (time, pressure and gas) profile only. The Doppler scores may be indicative of the risk for that particular group of individuals.

When incidence of DCS was plotted against the percentage of Doppler Grades III or above in each exposure group, the data showed considerable scatter as would be expected for small groups. At a percentage (within the group) of individuals with Doppler Grade III or above over 20%, there appears to be an elevated risk of DCS for the exposure group. However, the variation between small groups is substantial.

Data from a well controlled laboratory trial demonstrated the range of differences that can be obtained from groups of about 5 individuals with the same exposure. Subdividing an actual exposure of ten individuals into two subgroups of five individuals illustrated how two real subgroups of five individuals with exactly the same exposures could result in five individuals with 3 Grade 0 scores out of 15 (over 3 days of exposure), or five individuals with 14 Grade 0 scores out of 15 (over 3 days of exposure). The subset of individuals could radically affect how the acceptability of the decompression procedure might be regarded. The variability between small groups of individuals is likely to be relevant to modern compressed air tunnelling where small groups are the normal practice. The data from this trial also suggested that diving trial data may overestimate risk of DCS for given Doppler grade recorded in compressed air work.

Operational experience of Doppler monitoring

The chapter on operational considerations describes the principles and practice of health protection by a Contract Medical Adviser in a tunnelling project. It also describes the practical experience of application of Doppler monitoring on the Channel Tunnel Rail Link (CTRL).

Doppler monitoring on one tunnel of the CTRL produced results for nine miners. Their maximum recorded precordial Doppler grades were: 0 for 1 miner, I for 1 miner, II for 6 miners and III for 1 miner. Initial interpretation of the Doppler scores (based on the risks of given Doppler grade in diving trials) suggested a risk of DCS of about 5%. However, the historical compressed air work data on DCS rates for that level of exposure and duration (1.1 bar gauge pressure for 6 hours) indicated that DCS rates of about 0.2% were the general experience.

Individual susceptibility
A few individuals have a large proportion of the reported incidents of DCS in compressed air work e.g. recent and historical data suggest that 4% of the work force have 50% of the DCS incidents (Colvin, 2003; Golding *et al* 1960).

Attempts to identify susceptible individuals in the process of health screening have excluded most of the general physiological and health criteria for detecting susceptible individuals (Colvin, 2003). In recent years evidence has accumulated indicating a link between Patent Foramen Ovale (PFO) and some types of DCS.

Differences in susceptibility between individuals may be one of the causes of differences in DCS rates between data sets. For example, the diving trials may have been conducted with professional divers who are a survivor population of those who have not been excessively susceptible, whereas the hypobaric simulations of high altitude exposure of Conkin *et al* (1998) used volunteers who did not have apparent prior experience of hypobaric exposure and there would have been no removal of susceptible individuals by self selection. That might contribute to higher DCS rates being reported from the hypobaric trials than from the diving trials. Modern compressed air data may contain both "survivors" and new recruits.

If individual susceptibility to DCS is also linked to individual propensity to produce high Doppler scores, then a sequential record of each individual's Doppler scores might be a guide to susceptibility. This hypothesis, if confirmed, could lead to significant benefits in protecting the health of the (at present unidentifiably) susceptible individuals. Further research is needed to establish whether such a relationship does exist.

Use of Doppler for assessing decompression procedures
Lambertsen *et al* (1999), in discussing the application of their VGE-DCS-BGI relationship, wrote that "*Since VGE and DCS are different expressions of the complex results of decompression stress, their highly variable relations in laboratory dive trials and operational diving should not be the basis for predicting acceptably low risk in entire tables.*" They also considered that acquiring further data from "*monitoring of unknown profiles*" would have no cumulative value, and therefore dismissed acquiring data from routine monitoring of operational diving because most operational diving produces low decompression stress, and because relationships had relied on data from precisely monitored trials. However, for modern operational compressed air work, the decompression process can and should be well defined (giving well characterised profiles). Some of the operational profiles in compressed air work are not "low predicted decompression stress", nor are they low risk in terms of historical and modern data for DCS rates. Therefore, we suggest that data from Doppler monitoring of operational compressed air work could be of research value.

If Doppler monitoring is to be of value for routinely monitoring and controlling decompression stress, then there needs to be a sound basis for interpreting the Doppler scores in terms of health risk. To aid the interpretation of Doppler scores recorded for modern tunnelling, we suggest that there is a need to build up a data base of Doppler scores from operational compressed air work. These data, once collected, would define the scores which are associated with hyperbaric exposures and decompressions which have been shown to have very low DCS. They may also help to define the correlation between Doppler Scores and DCS in the compressed air work operational situation.

Conclusions

1. An association between grade of Doppler score and risk of DCS is evident from several data sets, but the actual level of risk is dependent on the data set used, for

good and valid reasons. The available evidence indicates that the breathing of oxygen during decompression leads to substantially lower risk of DCS for given Doppler grade than for air-only decompression.

2. Most of the data demonstrating an association between Doppler scores and risk of DCS originate from diving trials. There are only limited data from laboratory trials simulating compressed air work, and a very small amount of Doppler monitoring data from operational compressed air work. The practical experience indicates that it can be difficult to interpret Doppler scores in relation to risk of DCS in compressed air work, because of variability between individuals and small groups of workers. Therefore, a necessary precursor to applying Doppler monitoring as a routine monitoring tool would be to have adequate comparative data from operational conditions that are accepted as being low risk. However, at present, that is a research need rather than an operational requirement.

3. Since there are some operational profiles for compressed air work where DCS and dysbaric osteonecrosis are believed to be non-trivial risks, it is still appropriate to consider how Doppler monitoring might be used to check on the adequacy of decompression procedures in such circumstances.

4. Based on the very limited data available from operational compressed air tunnelling, and the data linking risks of DCS to grades of Doppler scores in controlled diving trials, an incidence of 20% or more of individuals with maximum Doppler Scores at Grade III or above should trigger careful review of the adequacy of the decompression procedures (e.g. to identify contributory factors or to modify the procedure appropriately). However, this is based on small amounts of data, and substantial variation in Doppler scores occurs between individuals and between small groups, even for identical decompression stress.

5. As stated by others, including Lambertsen *et al* (1999), the venous gas embolisms that produce Doppler scores are not causally related to DCS and therefore Doppler grades are neither a consequence nor a direct precursor of DCS. However, the risk of DCS associated with Grade IV Doppler score has been of the order of 50% in some of the data analysed for air-only decompression. Although the risk associated with Grade IV under oxygen decompression should be less than that from air-only decompression, there is still a case for the Contract Medical Officer to consider providing prophylactic recompression (i.e. recompression in the absence of any clinical symptoms) for those with Doppler Grade IV.

6. Collecting Doppler monitoring data involves the cost of the monitoring but also importantly requires non trivial amounts of time from the staff being monitored, and thus affects the availability of the compressed air team when maintenance or repair work on the tunnel boring machine (TBM) is needed. Downtime for the TBM is expensive for the tunnelling contractor. Collecting Doppler data for research purposes, from operational compressed air working, will be a significant cost and this report has not attempted to resolve the issue of how such work should be funded.

7. It is recognised that a small proportion (about 4%) of the compressed air workforce carry a high proportion (about 50%) of the incidence of DCS. These might be individuals who also have a propensity to high Doppler scores, although that is not proven nor is it an inevitable consequence of the association between higher Doppler grades and DCS incidence. This hypothesis could be tested if regular Doppler monitoring were undertaken. If confirmed, it might enable individuals at risk of DCS to be protected.

8. Given the present uncertainty over the clinical interpretation of Doppler scores, careful consideration has to be given as to whether and how individuals should be informed of their results. It has been recognised that release of other medical screening data can generate unnecessary or inappropriate anxiety, and even morbidity, and the same has been found to be true of Doppler scores (especially "high" scores).

9. Doppler monitoring has a valuable role in comparing the efficacy of different procedures in well controlled laboratory trials. It may perhaps offer a similar function in testing the benefit of changes in decompression tables or reductions in exposure time or pressure in operational conditions. However, the high levels of variability within and between individuals may make it more difficult to obtain unambiguous results when extraneous factors may be less controlled than in laboratory trials.

10. Lambertsen *et al* (1999) concluded that "*With the existence of high quality data bases, for both VGE* (Doppler scores) *and DCS, and their correlation via a validated stress index, it* <u>should be</u> *more practical to use the profile specific BGI stress index* (or other validated theoretical index of profile-specific stress, such as predicted gas in blood) *for examining operational tables profiles and operational time depth records than* it would be to use Doppler monitoring." However, in the data analysed for this study, Doppler monitoring provided information additional to that from theoretical predictions of decompression stress. Doppler monitoring may reflect individual or environmental ancillary decompression stress factors not covered by the theoretical modelling. The Doppler monitoring results may therefore better reflect the adequacy of the decompression procedure for the particular individuals in the specific circumstances.

Recommendations

On routine use of Doppler monitoring
Doppler monitoring is not a minor undertaking because it requires a substantial amount of time from the individual while being monitored after decompression. That is a practical issue which is likely to affect acceptability of routine monitoring, unless the monitoring has clear and proven benefits (e.g. to the individuals, in terms of prophylactic recompression when appropriate, and to the compressed air contractor in terms of reduced morbidity or more efficient procedures).

Doppler monitoring could usefully be undertaken at the start of a tunnelling contract and at the stages when the working conditions change (e.g. as the tunnel goes deeper and higher pressures become necessary). We recommend that this be adopted, to provide more data where it is currently lacking.

If an individual were Doppler Grade IV, then the risks of DCS (or possibly other health effects) might be large enough to justify prophylactic decompression. However, the evidence on the relative frequency of Grade IV in operational compressed air work is not available to justify a recommendation that monitoring become the normal practice.

On clinical guidance and protocol
If Doppler monitoring is to be undertaken, then it must be undertaken under a protocol agreed with management and with the workforce, and the informed consent of subjects must be obtained. For informed consent, the purposes of the monitoring need to be defined, and the possible consequences of any Doppler results need to be specified.

On long term health effects

We suggest that Doppler monitoring be regarded as a tool that might help to reduce decompression stress and thereby reduce long term health risks, but the proof of an association will be difficult and slow to obtain in the compressed air work force as long term health effects cannot be detected until years later and compressed air work is not a regular career for most tunnellers at present within the UK.

On procedures needed to obtain reliable and comparable Doppler data

Any implementation of Doppler monitoring needs to follow the good practice described in the review. Controlled and standardised techniques of measurement, with adequate external quality control, are essential if the monitoring is to produce adequately consistent and comparable data to be useful for establishing standards across the industry.

On data records, maximum scores and integrated scores

The Doppler scores in the published literature are mainly in terms of maximum Doppler grade from precordial monitoring. Doppler scores are generally recorded at intervals (e.g. signals recorded at approximately 20 minute intervals, and with 3 readings taken over an hour). Other summary indices could be constructed to use all the data, e.g. the three readings and the time intervals between readings. The maximum score may have been widely used, but an integrated score might have added value. We recommend that the data records include enough information to allow derivation of other summary indices such as an integrated score.

On practical issues

Any implementation of Doppler monitoring in compressed air tunnelling would need to take account of the practical issues described in the report.

The costs involved in Doppler monitoring are not trivial and would be a practical consideration. However, the purpose of this study has been to assess the technical merits and requirements, not the cost issues.

Table 5.4 Predicted volume of gas in bubbles (l/ml) and observed maximum bubble scores, precordial Doppler recording at rest. (Results produced by Dr Flook)

Each asterisk (*) in this table indicates an incident of DCS, either for the Doppler grade (in columns 3 to 7) or prior to Doppler score being recorded (* in column 2). All exposures involved immersion in water with the exception of the four marked as compressed air (CA). See text in section 5.3.1 for details. The pressure is given in metres sea water (msw); 10 msw is approximately equal to 1 bar gauge pressure.*

Maximum depth (msw)/ duration at maximum (mins)	Predicted gas (l/ml)	Grade 0	Grade I	Grade II	Grade III	Grade IV	Type of decompression
9/120	1.65	2	1	1			CA
18/80	1.82	7	1	1			Air, oxygen
27/60	1.96*	20	1		1		Air, oxygen
36/50	2.52*	12	2	4	6		Air, oxygen
24/34	2.55	8					Air, oxygen
19/60	2.56	10	1		1		Air
30/21	2.83	8					Air, oxygen
30/55	2.92	2	4	4	4		Air
24/30	3.06	8					Air
18.5/240	3.09	17	3	2	8		CA, oxygen
30/14	3.10	6					Air
45/40	3.11	7**	2*	1	1		Air, oxygen
45/40	3.27	19		1*	2		Air, oxygen
24/40	3.33	5	1				Air
33/15	3.48	8					Air
45/70	3.76	6	2	2	3		Air, Oxygen Sur-D
11/360	4.00	1	1	6	1		CA
54/30	4.06	19	1	3	1		Air, Sur-D
30/28	4.12	6	5	1			Air, Oxygen Sur-D

Maximum depth (msw)/ duration at maximum (mins)	Predicted gas (l/ml)	Grade 0	Grade I	Grade II	Grade III	Grade IV	Type of decompression
80/55	4.29	11	1				Air
36/30	4.30	5	3	3	1		Air
36/50	4.35	15	1	3	2		Air
36/50	4.41		1		5***		Air
36/50	4.44	18	2	3			Air
36/60	4.44	7		3			Air
36/40	4.45	2	2	3	5*		Air
45/20	4.77	2	3	1			Air, Sur-D
60/8	4.78	8					Air
70/6.8	4.81	1	2		1		Air
36/50	4.83	6	1	6*	6*		Air
66/10	4.92	12	1		1		Air
18.5/240	5.00	4		3	22	4*	CA
39.4/30	5.11	6	4	6	36	4	Air
45/25	5.12	7	2	2	1		Air
54/15	5.12	5	4	3			Air
60/9	5.27	9	2	2			Air
70/7.5	5.29	10	4	1	3*		Air
45/20	5.30	8	1	2	3		Air
75/10	5.30	6	1	1	2		Air
45/30	5.32	3	4	2	3*		Air
45/15.5	5.42	10	3	2	5*		Air
45/30	5.71*	5	1		4		Air
54/20	5.75	5	1		3		Air
60/10	5.75	9	1	2			Air

Maximum depth (msw)/ duration at maximum (mins)	Predicted gas (l/ml)	Grade 0	Grade I	Grade II	Grade III	Grade IV	Type of decompression
45/40	5.82	8	2	2	8***		Air
54/20	5.88	3	1	3	4	1	Air
54/25	6.10	3		4			Air
54/25	6.10	1	1	4	5	1	Air
66/15	6.18	6	3		5		Air
54/25	6.66	1		3	1		Air
63/30	6.77	11		4	6		Air, Sur-D
63/30	7.60	5	2	4	1		Air, oxygen, Sur-D
72/40	7.69	10	1	4	6		Air, Sur-D
Total	3 (with no Doppler grade available)	393	80	102	167	10	Total = 755 (752 exposures with Doppler grades)