Evaluation of decompression tables by Doppler technique in caisson work in the Netherlands.

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Breedijk JH, Van der Putten GJGM, Schrier LM, Sterk W. Evaluation of decompression tables by Doppler technique in caisson work in the Netherlands. Undersea Hyperb Med 2009; 36(1):19-24. Introduction: Hyperbaric work was conducted for constructing an underground tramway in the Netherlands. A total of 11,647 exposures were conducted in 41,957 hours. For these working conditions specifically developed oxygen decompression tables were used. Methods: Fifteen workers were submitted to Doppler monitoring after caisson work at a depth at 12 msw. Measurements were done according to the Canadian DCIEM protocol. For bubble grading the Kisman-Masurel 12-points ordinal scale (0-IV) was used. Results: Bubbles were detected in 17 of the 38 examinations. The highest grade (III-) was found in four measurements. At rest the grading was never higher than I+. Two hours after decompression the grading was remarkably higher than after one hour. Conclusions: Bubble scores were relatively low, although the maximum grading probably is not reached within two hours after decompression. It may be concluded that the oxygen decompression tables used, were reliable under these heavy working conditions. At group level, decompression stress can be evaluated by Doppler monitoring. In order to reduce health hazard of employees, use of oxygen during decompression in caisson work should be embodied in the occupational standard.

INTRODUCTION

From September 2001 to April 2003 hyperbaric work was conducted for constructing an underground tramway in The Hague, the Netherlands. The construction method was excavation by digging, without the use of a tunnel boring machine. The length of the underground section was 1250 m. A total of 11,647 man-compression exposures were conducted to a maximum depth of 14 metres seawater (263 kPa(a)) and the total compression period took 41,957 hours. Two hundred tunnel workers were employed in this caisson project.

Tunnel workers are exposed to compressed air for an extended period and are at risk of developing decompression illness (DCI). The formation of bubbles in body fluids and tissues is considered to be one of the contributory factors of DCI. The risk of DCI does appear to be increased and related to the amount of bubbles observed. Because of the relationship between bubbles and the probability of developing DCI, the detection of circulating venous gas emboli (VGE) is considered as a useful index to evaluate or compare different profiles or decompression procedures for the safety at group level (1).

In this study, we evaluate the reliability of oxygen decompression tables used for the compressed air workers. These tables were specifically developed for this project. The effects of hyperbaric exposure were evaluated by using the Doppler technique to detect decompression-generated bubbles.

METHODS

Subjects

Construction workers, inexperienced to hyperbaric work, underwent a thorough medical history and physical examination in accordance with national regulations for compressed air work (2). A group of 200 male labourers were selected and instructed to work in compressed air conditions. They were informed about the decompression procedures. Professions of the workforce were: engine-driver, plait-worker, carpenter, demolisher, electric welder or a combination (various). A group of 15 workmen participated in the Doppler study. During the study period, work was conducted at a maximum depth of 11.4 msw (214 kPa(a)) and the average exposure time per shift was 302 minutes (177-319 minutes). Biometrical characteristics were as follows :

(mean ± SD): age (34.9 ± 7.0 yr), weight (81.9 ± 9.5 kg), height (180.7 ± 9.1 cm) and Body Mass Index (BMI) (25.2 ± 3.3 kg.m-²).

Table 1 shows the physical characteristics and the professions of the study population. Of these 15 workers, one person (F) withdrew prior to completing the study because he was no longer available one hour after decompression and monitoring. The remainder of the group completed all four examinations in the study period of four days (Thursdays and Fridays) in two weeks consecutively. An examination is defined as a series of the total of four Doppler measurements in one day in one subject: a measurement at rest and one respectively after movement, both one and respectively two hours after decompression.

In total 150 measurements were done; 37 complete examinations and one incomplete one (37 x 4 + 1 x 2 = 150). Most workers were more than once in the shifts during the study period and so in the examinations.

Subject	Age (yr)	Ht (cm)	Wt (kg)	BMI (kg.m-²)	Profession
A	27	188	95	26.88	engine-driver
B	32	191	87	23.85	engine-driver
C	27	180	75	23.15	demolisher
D	37	181	64	19.54	plait-worker
E	39	175	71	23.18	plait-worker
F	46	170	93	32.18	various
G	27	190	90	24.93	carpenter
H	39	182	91	27.47	plait-worker
I	40	193	93	24.97	carpenter
J	31	181	85	25.95	various
K	27	176	74	23.89	various
L	27	190	80	22.16	electric-welder
M	47	165	78	28.65	plait-worker
N	38	165	80	29.38	plait-worker
O	39	183	72	21.50	plait-worker

Table 1. Physical characteristics and professions of the subjects.

Decompression tables

This caisson project was characterised by a hyperbaric working profile at a maximum of 1.4 bar (gauge) pressure during long exposure times of six hours per shift. When using air decompression tables in these conditions, the decompression duration would take too long, making it less safe for the health of the employees and less commercially useful. The decompression schedules applied for constructing this underground tramway were specifically developed for a maximum pressure at 14 m, particularly for heavy physical labour. When the study was performed, the depth was 11.4 m and the decompression table for a maximum depth of 12 m (equivalent to 1.2 b) was used. The table is based on the use of 100% oxygen during the decompression stop. Oxygen table Cox12/360© (table 2) was used when the compressed air exposure time did not exceed 360 minutes. On one occasion, six workers were decompressed using another oxygen table, although their exposure time was less than 320 min. In this shift, table Cox12/420© was used because four other workers, who did not participate in the Doppler study, exceeded the maximum exposure time of the Cox12/360© table (372 min). Oxygen was administered for 30 min at 0.3 bar (g) pressure (in table Cox12/420© oxygen for 40 min). In case of oxygen supply failure, the air compression table Cai12© acts as back up, prolonging the decompression time to 225 min. The decompression rate was maximum 1 bar per minute. The calculated unit pulmonary toxic dose (UPTD) was respectively 46 and 62 per oxygen decompression using the aforementioned tables (table 2).

exposure time (min)	Stops (min): pressure in bar (g)				total UPTD
	0.6 oxygen	0.3 oxygen	0.3 air	0.3 oxygen	
360		30	-	-	46
420		40	-	-	62

Table 2. Oxygen decompression tables Cox12/360© and Cox12/420© developed for a maximum working depth to 12 msw.

Data collection

Fifteen tunnel workers were submitted to non-invasive Doppler ultrasonic monitoring for venous gas emboli. Doppler assessments were performed with a continuous-wave Doppler DBM9008 ultrasonic device, with an array probe of 2.5 MHz (Techno Scientific, Toronto). Doppler sound recordings were stored on an Aiwa F5 mini-disc recorder for later analysis.

Measurements were done precordially (right ventricle) according to the Canadian Defence and Civil Institute of Environmental Medicine (DCIEM) protocol (3); both in standing position at rest and three times after a specified movement, a deep knee bend. In total, 37 complete series of four measurements were done one and two hours after decompression, distributed over four days (6, 7, 13 and 14 June 2002, on Thursdays and Fridays). There was also an incomplete series of only 2 measurements i.e. after one hour at the second study day. This subject was not available for further examination. The study took place in a period when the workers were daily exposed to compressed air, five consecutive days a week.

The employees had to work on a regular base, on weekdays in daytime, not during weekends. The Doppler measurements started in the week when the excavation was at the level of the deepest section of the tunnel at the beginning of that week. In total this took two weeks of working (also the study period), after that stage the excavation was less deep. In the timetable of the caisson project, the study was conducted midway between the start and the end (10 months respectively). Bubble grades were evaluated using the Kisman-Masurel 12-point ordinal scale (KM code). The KM classification system for quantification of the different bubble loads is divided into three separate components: frequency, amplitude and percentage of cardiac cycles with bubbles/ duration of bubbles. Each component is graded separately as a single-digit non-parametrical bubble grade from 0 to IV indicating no bubbles to maximum bubble activity. To minimize subjectivity, all Doppler audio records of the bubbles detected were scored by two independent well-trained Doppler-examiners. One of the examiners performed 'blind' grading on all measurements.

RESULTS

Bubbles were detected in 17 of the 38 examinations. In 20 of this series of four measurements, no observable bubbles were found at all, neither at rest, after movement nor after one or two hours after decompression. This concerned five subjects (C, E, F, K, and M) although two persons (E and K) participated in only one working day during the two weeks

				1 hour		2 hours	
Date 2002	Subject	Exposure time (min)	Table m/min	At rest	Movement	At rest	Movement
June 06 Thursday	A	313	12/360	0	2	1	2
	H	177	12/360	0	0	0	2
	J	313	12/360	0	2	1	3-
	B	304	12/360	0	1	0	2-
	G	306	12/360	0	2	1+	2
	I	304	12/360	0	0	0	2-
	N	304	12/360	0	1+	1	2
June 07 Friday	A	315	12/360	0	1	0	2
	D	315	12/360	0	1	0	0
	H	309	12/360	0	0	0	3-
	J	315	12/360	0	2	1	3-
	B	306	12/360	0	1	1	2-
	G	306	12/360	1-	1	1	2
June 13 Thursday	H	311	12/420	0	1	0	3-
	J	319	12/420	1	2	0	1
	L	319	12/420	0	0	0	2
June 14 Friday	O	303	12/360	0	0	0	1

Table 3. Results of the Doppler bubble detection grading according to the Kisman-Masurel code. Measurements one and two hours after decompression, at rest and after movement.

of the study. In the incomplete series on the second study day, the two measurements were both negative one hour both after rest and movement (F, not shown in table 3). Bubbles were repetitively found in another five workers (A, B, G, H, and J). Two of them showed the highest bubble grade detected (III-), two hours after decompression including movement (H and J). At rest, the grading never exceeded I+. Two hours after decompression the bubble grading was remarkably higher than after one hour at group level (except for D on June 07 and J on June 13). A selection of the recorded results of Doppler bubble detection in the subjects is given in table 3. Examinations are not shown in the table in case all four measurements were graded 0. Figure 1 shows the total distribution of the grading.

Among the 15 tunnel workers, no statistical difference in terms of biometrical characteristics (age, weight, height or BMI) or workload (profession) was found in correlation to the bubble grading (table 1) (negative correlation coefficient, and/or not significant, $p>0.05$).

During the caisson project, two cases in the total population being exposed to hyperbaric working conditions, were treated for the possibility of having symptoms of DCI. These cases did not occur during the study period or in the study population. In one case before starting work a workman reported transient soreness in

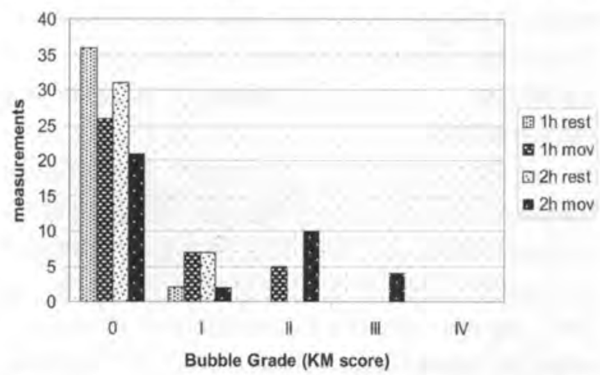

Fig. 1 Histogram indicating the Doppler grading (KM code) and the number of measurements per different examination (at rest, after movement, one and two hours after decompression).

one shoulder and elbow. The symptoms were provoked by private drilling work done after a shift of caisson work and attributed to DCI. Another caisson worker reported vague complaints of pain the night after working, interpreted as doubtful unilateral shoulder and elbow bends. Both were preventively treated by routine recompression according to decompression table Comex12© (4) with no recurrence of symptoms.

DISCUSSION

It is no common use to evaluate decompression schedules in every tunnel or caisson work by the Doppler technique for grading the decompression-generated bubbles existing in employees exposed to hyperbaric conditions. Our study questions were whether this could practically be done in order to monitor the health hazard of a group of compressed air workers and whether the oxygen decompression tables were reliable in these working conditions or whether the tables needed to be adjusted.

Bubble scores graded in this study were relatively low; 37 positive grading of the total amount of 150 measurements (24.7%). At rest the score was never more than I+, as the highest bubble grade (III-) was only found in four measurements (2.7%), after movement two hours after decompression. Although the participation of the workmen differed depending on the shifts they were scheduled, at group level this concerned four measurements in four different examinations (4/38=10.5%) or four examinations in the workforce (4/15=26.7%) or 4 measurements in two subjects (2/15=13.3%). The Doppler score two hours after decompression was, in most subjects, higher than after one hour. In our study it was not possible to prolong the measurement period to the preferred three, or even more hours after decompression. This was because the workmen, who volunteered in the study, were no longer available for examination two hours after decompression and ending their shift. In a study conducted by Flook (5, 6) it was not unusual for the first bubbles to appear as late as one hour after oxygen decompression. The peak bubble counts were usually observed between 90 and 120 min and could remain unchanged for 2-3 hours (1). VGE can persist for several hours after decompression. The delay time is highly dependent on the severity of the profile, i.e. exposure of compression (duration and pressure) including working activity. It may be suggested from our study that according to the 'dive' profile (relative shallow depths and long duration) bubble formation did not reach its maximum in some workmen. Moreover, the maximum bubble grading at a specific time is not an indication of the duration or time distribution of the bubble load.

For evaluation of decompression tables, the Doppler technique can be performed to obtain comparative or relative information of bubble activity. Bubble detection cannot be used as a predictive tool for DCI especially not in individual subjects. Although DCI is often associated with VGE, VGE is not highly correlated with DCI symptoms. There is a great inter- and intra-variability in the detection of bubbles and symptoms among different subjects at different times. Some individuals are more prone without developing symptoms of DCI (H and J in this study). On the other hand 'low bubblers' may show signs of DCI (1).

Other factors contribute to variation in the response are fatigue, age, obesity, dehydration, level of fitness, workload etc. There was no statistically significant correlation found in our study, probably because of the limited population size.

Exertion after decompression is not recommended because of the possibility that the VGE peak is not reached, and movement will provoke bubbles. The case of DCI resulting from drilling after caisson work demonstrates this. Moreover only 2 possible cases of DCI out of 11,647 man-compressions may suggest relatively low exposure stress and/or adequate decompressions.

Compressed air workers should be carefully selected and instructed to act as safely as possible in these specific working conditions.

To evaluate risks of DCI in hyperbaric projects the workforce should be urged to report physical complaints (7). To obtain greater compliance, the workers should be allowed to respond anonymously, otherwise there might be chance of underreporting because workers may feel that they might be penalized if they report reducible. Besides the pressure exposure profile the planned workload has to be taken into account. The use of oxygen decompression tables is not yet a standard procedure in all tunnels or caisson work. In comparison with air decompression, oxygen tables reduce the decompression time impressively. In our study, the reduction in decompression time is a few hours, from 225 min on air decompression to 30 min on 100% oxygen decompression. Also the cost benefits are evident. After all, oxygen decompression seems to be the only viable and practical method for safely decompressing tunnel workers (8*).*

According to the very low incidence of reported symptomatic DCI and the relative low bubble grading found at group level, the oxygen decompression tables used in these heavy working conditions did not require adjustment. It may be concluded that the oxygen decompression tables developed by Sterk, used in this caisson project, were reliable. The use of Doppler monitoring during the execution of a hyperbaric project and the use of 100% oxygen during decompression are yet little put into practice. Monitoring health risk, after compressed air exposure of a group of tunnel and caisson workers, could be practically performed by the use of the non-invasive Doppler technique. Decompression tables could be evaluated and if necessary might be adjusted to the working conditions. It would be desirable to commonly allow the use of oxygen during decompression in order to reduce health hazard of compressed air workers. This might be included in the occupational health assessment of compressed air work and also might to be confirmed by legislation.

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