Manifestations and treatment of 793 cases of decompression sickness in a compressed air tunneling project in Hong Kong

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Lam TH, Yau KP. Manifestations and treatment of 793 cases of decompression sickness in a compressed air tunneling project in Hong Kong. Undersea Biomed Res 1988; 15(5):377–388.—In the largest compressed air tunneling contract for the construction of the Island Line of the Mass Transit Railway system in Hong Kong, 154,390 man-decompressions occurred, of which 142,140 were after exposures to 1 bar (1.97 ATA, 14.7 psig) or above. The maximum working pressure (MWP) was 3.30 bar (4.26 ATA, 47.9 psig). There were 792 cases of type I and 1 case of type II decompression sickness. The manifestations of the cases were generally similar to those reported elsewhere. Oxygen treatment was given to 9 cases and all were successfully treated with no recurrence of symptoms. Minimum effective pressure treatment on 783 type I cases was successful, with 9.6% requiring two or more recompressions. The pressure required to relieve symptoms was more closely related to the interval between completion of decompression after work and commencement of treatment than to the delay between onset of symptoms and treatment. For every 1-h interval or every 1-h delay, an additional pressure of 0.04 bar (0.04 ATA, 0.58 psi) above MWP was required for pain relief. Step-wise multiple regression analysis showed that the four predictors for pressure of relief and the highest pressure used in recompression, respectively, were, in order of descending importance, maximum working pressure, interval before treatment, bends sequence (the n^th^ attack of bends experienced in the present contract, i.e., the sum of previous attacks and the present attack), and duration of exposure.

decompression sickness · manifestations · treatment · oxygen · compressed air workers · compressed air tunneling · caisson

Use of compressed air in the construction of underground tunnels for the Mass Transit Railway (MTR) system in Hong Kong started in 1975. By 1985, three phases of the construction were completed: a) Modified Initial System, b) Tsuen Wan Extension, and c) Island Line. Guidelines in the British Code of Practice for Work in Compressed Air were followed in enacting special legislation for protecting the health of compressed air workers. The Blackpool Tables were adopted for decompression procedures (1). Decompression sickness (DCS) was scheduled as a reportable occupational disease.

Construction of the tunnels was done by different construction companies, each contracted to work on one section of the system. An appointed physician was responsible for medical examination of compressed air workers, control of the medical services on sites, treatment of DCS, supervision of medical lock attendants, and keeping of medical, compression, and decompression records. The Occupational Health Division of the Labour Department was the government advisory and supervisory agency, and the Factory Inspectorate was responsible for overseeing work practice and ensuring compliance with the legislation.

Lam and King (2) studied the relationship of obesity and susceptibility to type I bends in expatriates working in compressed air during the first phase of construction. Two unusual cases of dysbarism during construction of the second phase were reported by Lam and Yau (3). Lo and O'Kelly (4) reported on the health experience of compressed air workers in Hong Kong as a whole, based on data reported to the Occupational Health Division. In the largest tunneling contract, the preliminary experience in preemployment medical examinations was reported by Lam et al. (5), and Lam and Yau (6) subsequently reported on medical examinations and surveillance of compressed air workers. Lam and Yau (7) also reported on the incidence of DCS in that contract.

In this paper, we report the clinical characteristics of 793 cases of DCS during construction of the Island Line, and our experience in treating these cases. The objectives were a) to describe the clinical manifestations of the cases and to compare with series elsewhere; b) to describe and evaluate the two methods of treatment used; and c) to study the factors associated with the pressures used in recompression treatment. The effects of maximum working pressure (MWP) and duration of exposure on the incidence of DCS were previously reported elsewhere (7). The effects of other risk factors or variables on the occurrence of DCS will be dealt with in another paper.

MATERIALS AND METHODS

Construction of different sections of the Island Line was undertaken by different contractors. The present study is concerned with the largest contractor, the only one employing a full-time compressed air physician (KPY) for preemployment medical examination and prevention and treatment of DCS. Complete medical records were kept for all workers. These records, together with our first-hand involvement, made a more detailed and reliable analysis possible. Lo and O'Kelly (4) only analyzed notification data from several contractors but the completeness and quality of the data varied among different contractors.

In the present contract, compressed air work started on 17 October 1982 and ended on 21 May 1984. The total number of working days using compressed air was 583. The total number of man-shifts was 141,361. The mean number of workers exposed per day was 242.5. The mean number of decompressions per man per shift was 1.09. Only a small proportion (less than 10%) of men were exposed to compressed air more than once per shift, each for usually less than 4 h (excluding decompression time). The unit of pressure used in Hong Kong, in accordance with the British Code of

Practice, was bar, which is a pressure gauge measurement (1 bar = 0.987 ATA = 14.504 psig). Maximum working pressure used was 3.30 bar (4.26 ATA, 47.9 psig). Preemployment medical examinations were carried out on 1916 men, and 367 (19.2%) of them were found to be unfit for employment in compressed air work, mainly due to lung and cardiovascular diseases (6).

All workers were encouraged to report any ailments after decompression to the Compressed Air Medical Centre, even if their symptoms were not serious. Decompression sickness was defined as type I if the symptoms were confined to limb pains, skin mottling, or mild, nonspecific symptoms. Type II sickness was one that showed signs and symptoms of nervous, respiratory, cardiovascular, or alimentary system involvement.

Table 1 shows the distribution of man-decompressions by MWP and duration of exposure in compressed air, together with occurrence of bends and bends rate. The bends rate increased with higher MWP and longer duration of exposure.

All treatments were done in a medical lock that could be compressed up to a pressure of 10 bar. The provision of the chamber complied with the specification of the British Code of Practice. Most treatments were air treatments, but a few were oxygen treatments.

The procedures for air treatment generally followed the British Code of Practice with a small modification. The Code of Practice recommends recompressing the patient to 0.1 bar above MWP and, if pain persists, to raise the pressure by 0.1 bar for each 15-min interval until the pain is relieved. In the modified procedure, we raised the pressure by 0.5 bar at a shorter interval of 1–2 min and observed the response of the patient. A pressure of 1.0–2.0 bar above MWP could be achieved in about 5–10 min. When the pain was relieved, the pressure was maintained for 15–20

TABLE 1

BENDS RATE BY MAXIMUM WORKING PRESSURE AND DURATION OF EXPOSURE

Maximum Working Pressure, bar	Exposure < 4 h			Exposure 4–8 h		
	No. of Decompressions	No. of Bends	Bends Rate, %	No. of Decompressions	No. of Bends	Bends Rate, %
0.10–0.49	167	0	0	175	0	0
0.50–0.99	6,370	0	0	5,538	0	0
1.00–1.49	14,769	1	0.01	23,891	22	0.09
1.50–1.99	8,591	2	0.02	11,217	54	0.48
2.00–2.49	23,699	35	0.15	38,917	443*	1.14
2.50–2.99	7,034	35	0.50	12,882	182	1.41
3.00–3.30	251	3	1.2	889	16	1.80
Total	60,881	76	0.12	93,509	717	0.77
Total for 1 bar or above	54,344	76	0.14	87,796	717	0.82

*Including 1 case of type II DCS.

min. The decompression procedure then followed the Code of Practice. For type I cases, pressure was reduced at the rate of 1 bar every 2 min to half the MWP, then reduced to atmospheric pressure at the rate of 0.1 bar every 25 min. For type II cases, the effective pressure was maintained for 30 min and then reduced to 1 bar at the rate of 0.1 bar every 25 min. Pressure of 1 bar was maintained for 4 h then reduced to 0.5 bar at 0.1 bar every 45 min. Pressure of 0.5 bar was maintained for 1.5 h and then reduced to 0.2 bar at 0.1 bar every 45 min. This pressure was for 1 h, and the pressure of 0.2 bar was reduced to atmosphere at 0.1 bar every 45 min (1).

A few workers were given hyperbaric oxygen (HBO) therapy on a trial basis, closely supervised by the compressed air physician. An automatic oxygen dumping system (developed by K. Sato of Asahi Senkun, Japan) was connected to the chamber. Oxygen was delivered from oxygen cylinders by a two-stage pressure reduction so that oxygen was delivered into the chamber at 10 bar. The breathing face mask used by the patient was close fitting to prevent leakage. Oxygen was exhaled through a dumping valve to the outside of the chamber. For HBO therapy, the U.S. Navy Table 5 was used. The pressure used for recompression was 1.8 bar.

To study the relationship of recompression pressures as dependent variables with other independent variables, step-wise multiple regression procedures were performed using the Statistical Packages for the Social Sciences (SPSS) to obtain the best linear prediction equation (8). The criterion for selecting an independent variable in the equation was that the incremental sum of squares due to the variable was the greatest among other variables not already in the equation, subject to the conditions that the overall F of the equation and the F for including an additional independent variable were statistically significant.

RESULTS

We treated 792 cases of type I and 1 case of type II DCS in the medical lock. There were 483 men who had one or more attacks of bends: 318 had one attack, 95 had two, 36 had three, and 34 had four or more. The mean age was 29.2 yr (SD = 5.44). No association was found between the age of a man and the number of attacks of bends that he experienced.

Distribution of the 793 cases by nationality was Chinese 78.3%, Japanese 16.5%, others 5.2%. Distribution by occupation was miners 51.5%; fitters, riggers, welders 7.4%; electricians, carpenters, caulkers, shot-firers, concreters, laborers, operators, technicians 7.6%; general foremen (pit bosses) 6.2%; engineers 17.2%; surveyors 1.6%; inspectors and other workers not employed by the present contract 8.6%.

Seven hundred and sixty-nine cases (97%) occurred after single exposure to compressed air, 21 cases (2.6%) after two exposures, and 3 (0.4%) after three exposures within a shift. Distribution of cases by shifts was day shift 49%, swing or back shift 32%, and night shift 19%. Between 13.6% and 18.0% of the cases occurred for each day, Monday through Saturday whereas 8.2% of the cases occurred on Sunday.

Within the first five shifts in new starters we found 140 cases (18%), and 26 cases (3%) within the first five shifts in those returning to work after absence from compressed air for 7 d or more. Of the above, 71 did not follow the "acclimatization" procedures, which were trial procedures for the workers specifying that new starters or absentees after 7 d or more should only work from shorter to longer duration in compressed air for the initial shifts in steps of 4, 4, 6, 6, 8, 8-h shifts. Workers who were problem-free after this trial period were allowed to work the normal 8-h shifts in compressed air. The length of the shift is the exposure time in compressed air, excluding decompression time. Workers who had problems had to go through a longer trial of short exposures or be recommended as unfit for compressed air work, depending on the nature and severity of their problems.

Only 9 cases had a history of infection with "colds" before starting work, 9 cases had a history of injury of affected part of the anatomy, and 7 cases had a history of excessive use of the limbs. One case occurred after decanting and another case after decompression which did not follow the prescribed tables.

Of the 792 cases of type I bends, 749 (94.6%) had symptoms of localized joint pain or muscle ache only. Only 4 cases had skin mottling, whereas the others had mild and nonspecific symptoms of headache, nausea, vomiting, etc.

It was common for more than 1 part of the body to be affected: 133 cases, left knee only, 151, right knee only, 83 one site only other than the knees, and 426 (53.7%), more than 1 site. Table 2 shows the frequency of pain affecting various sites. The most frequently affected sites were the knees (55.5%) and the legs (14.6%). Both the right and left sides were affected to a similar extent. The lower limbs were much more frequently affected than the upper limbs: 55 cases (6.9%), upper limbs only; 669 cases (84.4%), lower limbs only; 55 cases (6.9%), both upper and lower limbs; and 14 cases (1.8%), other sites.

Table 3 shows the frequency and cumulative frequency of duration before onset of symptoms. Symptoms started during decompression in 11 cases and just after decompression in 229 cases. In almost all cases (790) symptoms started within 12 h after decompression.

TABLE 2
SITES OF PAIN: FREQUENCY OF BEING AFFECTED

	Right Side	Left Side	Total	
	No.	No.	No.	Percent
Shoulder	41	46	87	6.0
Arm	9	10	19	1.3
Elbow	34	19	53	3.6
Forearm	3	3	6	0.4
Wrist	5	7	12	0.8
Hip	39	29	68	4.7
Thigh	45	49	94	6.5
Knee	398	409	807	55.5
Lower leg	106	106	212	14.6
Ankle	41	48	89	6.1
Other	3	3	6	0.4
Total	724	729	1453	99.9

One or more sites may have been affected in one attack of DCS.

TABLE 3

FREQUENCY AND CUMULATIVE FREQUENCY PERCENTAGE OF DURATION BEFORE ONSET OF SYMPTOMS

Onset of Symptoms, h	No. of Cases	Percent	Cumulative Frequency, %
During decompression	11	1.4	1.4
Immediately after decompression	229	28.9	30.3
0.2–0.9	79	10.0	40.2
1.0–1.9	166	20.9	61.2
2.0–2.9	105	13.2	74.4
3.0–3.9	64	8.1	82.5
4.0–4.9	60	7.6	90.0
5.0–5.9	28	3.5	93.6
6.0–6.9	26	3.3	96.8
7.0–7.9	12	1.5	98.4
8.0–8.9	5	0.6	99.0
9.0–9.9	2	0.3	99.2
10.0–10.9	2	0.3	99.5
11.0–11.9	1	0.1	99.6
12.0–12.9	2	0.3	99.9
13.0 or higher	1	0.1	100.0
Total	793	100.1	

All cases were treated by recompression in the medical lock immediately after the workers reported symptoms to the medical center. The mean interval from the time when decompression finished after work to the time when treatment commenced was 6.52 h (SD = 4.65) (hereafter referred to as "interval before treatment"). The interval from the time when symptoms started to the time when treatment commenced was the "delay in treatment." The mean delay was 4.85 h (SD = 4.75). The interval before treatment was the sum of the duration between the end of decompression and onset of symptoms ("duration before onset of symptoms") and the delay in treatment.

Oxygen treatment was given in 9 cases. These men had worked in a MWP ranging from 2.00 to 2.98 bar (mean = 2.46 bar, SD = 0.30) for 3.8 to 8.0 h (mean = 6.1 h, SD = 1.66). Maximum pressure used was 1.8 bar. Mean duration of treatment was 2.37 h (SD = 0.24). Treatment for all cases was successful, with no residual symptoms or complications. No prior selection criteria for oxygen treatment was applied. These 9 cases were treated when the compressed air physician was available for direct supervision and when the necessary back-up support of medical attendants and equipment was ready. Thus, selection of these cases could be considered as random.

One case of type II DCS was treated successfully using the British Code of Practice. This was a vestibular case with symptoms of dizziness and vertigo after working for 7.4 h at 2.45 bar. Symptoms were relieved after recompression to 4 bar; total duration of treatment was 25.5 h. Only one recompression was needed.

All the remaining 783 type I cases were treated by recompression in air with the modified method, i.e., faster recompression to a higher pressure until the pain was relieved. This method was found to be more effective than the slower recompression recommended in the British Code of Practice. Results showed that when the pressure was increased rapidly up to a high enough level, the patient experienced a sudden disappearance of the pain and the diagnosis of DCS was obvious. For most cases, disappearance of the pain was complete. In a few cases, although the pain was not relieved completely, the change and improvement were remarkable. In 91 cases, the pressure of pain relief when the patient was recompressed was lower than the MWP. In 270 cases, the pressure of relief was up to 0.5 bar above MWP; 217 cases required 0.51–1.0 bar, 116 cases 1.01–1.50 bar, and the remaining 89 cases 1.50–2.90 bar above MWP. The mean pressure of relief was 0.57 bar above MWP (SD = 0.75).

As for the highest pressure used in recompression, 354 cases were recompressed to 0.01–0.50 bar, 217 cases to 0.51–1.00 bar, 120 cases to 1.01–1.50 bar, and 92 cases to 1.51–2.90 bar above MWP. The mean was 0.68 bar above MWP (SD = 0.59).

In 708 (90.4%) cases, treatment was successful with 1 recompression. However, as a result of recurrence of symptoms during decompression, 64 (8.2%) cases required 2, and 11 (1.4%) cases required 3 or more recompressions. The pressure of relief for the 2nd or 3rd recompression was mostly below the highest pressure used for the first recompression. Duration of treatment ranged from 3.1 to 39.7 h, with a mean of 9.82 h (SD = 4.46). All cases were treated successfully with no permanent disability, although 10 cases had mild residual symptoms after treatment. These were treated by analgesics.

After treatment each man was evaluated by the compressed air physician for fitness to continue compressed air work. Ninety-eight cases (12.4%) were disqualified, mainly because of attacks of DCS during the initial period of compressed air work or frequent attacks of DCS within a short time. The remaining were considered fit to continue.

Simple correlation analysis showed an association between pressure of pain relief in recompression treatment with MWP (correlation coefficient $r = 0.278$, $P < 0.001$) but not with duration of exposure to compressed air work ($r = -0.025$, $P = 0.45$). Similar results were obtained for the highest pressure used in recompression treatment with MWP ($r = 0.396$, $P < 0.001$) and with duration of exposure ($r = -0.051$, $P = 0.16$).

Table 4 shows the results of correlation analysis between recompression pressures with the interval before treatment and delay in treatment, respectively. The values of r were higher for the interval before treatment than for delay in treatment. The highest r was found between pressure of relief above MWP and interval. The linear regression equation was calculated:

$$\text{Pressure of relief above MWP (in bars)} = 0.3105 + 0.0397 \times \text{interval before treatment}.$$

For every 1-h interval between the end of decompression and when recompression treatment commenced, an additional pressure of 0.0397 bar above MWP was required to relieve the pain of the DCS. Similarly, because the slope for delay was 0.0395, for each hour in delay, an additional 0.0395 bar above MWP was required for pain relief.

Table 5 shows the summarized results of step-wise multiple regression for the two dependent variables of (*A*) pressure of pain relief and (*B*) the highest pressure used in recompression treatment, respectively. The 14 independent variables studied were

TABLE 4
CORRELATION BETWEEN THERAPEUTIC RECOMPRESSION PRESSURES WITH INTERVAL BEFORE TREATMENT AND DELAY IN TREATMENT, RESPECTIVELY

	Interval Before Treatment*		Delay in Treatment**	
	r	Slope	*r*	Slope
Pressure of pain relief	0.2276	0.0327	0.2116	0.0342
Highest pressure used	0.1772	0.0211	0.1735	0.0232
Pressure of pain relief above MWP	0.3831	0.0397	0.2507	0.0395
Highest pressure used above MWP	0.2538	0.0281	0.2296	0.0286

All the *r*'s (correlation coefficients) were statistically significant with $P < 0.001$; slope = change of pressure (e.g., of pain relief) in bar per hour of interval or delay.

*Time between decompression finished and treatment started. **Time between onset of symptoms and treatment started.

TABLE 5
SUMMARIZED RESULTS OF STEP-WISE MULTIPLE REGRESSION ANALYSIS OF DEPENDENT VARIABLES OF (A) PRESSURE OF PAIN RELIEF AND (B) HIGHEST PRESSURE USED IN RECOMPRESSION WITH 14 INDEPENDENT VARIABLES*

Step	Variables	Multiple, R	R^2	R^2 Change
	A. Pressure of pain relief			
1	Maximum working pressure	0.2746	0.0754	0.0754
2	Interval before treatment	0.3765	0.1418	0.0663
3	Bends sequence	0.3983	0.1587	0.0169
4	Duration of exposure	0.4078	0.1663	0.0077
	Overall $F = 38.76$, $P = 0.0001$			
	B. Highest pressure used			
1	Maximum working pressure	0.3934	0.1548	0.1548
2	Interval before treatment	0.4507	0.2032	0.0484
3	Bends sequence	0.4720	0.2228	0.0197
4	Duration of exposure	0.4800	0.2304	0.0076
	Overall $F = 58.15$, $P = 0.0001$			

*Only 4 variables were included in the multiple regression equation; the other 10 variables were not included because of lack of statistical significance.

MWP, duration of exposure to compressed air at work, number of exposures in the shift, the interval before treatment, age, nationality (Chinese, Japanese, others), work activity (manual or supervisory or other), occupation (miner or other), whether the worker was a new starter in compressed air (yes or no), whether the worker had been absent from compressed air work for more than 7 d or more (yes or no), whether there was any change in MWP when compared with the past five shifts (yes or no), change in duration of exposure with past five shifts (yes or no), acclimatization program followed by the worker (yes or no), and bends sequence (the n^{th} attack of DCS experienced in the present contract, e.g., the 1st attack experienced by the worker was 1, the 2nd attack was 2, and so on; the value of *n* was the sum of previous attacks, if any, and the present attack). Only four variables were found to be predictors in the multiple regression equation; the others were not included in Table 5 because they were not statistically significant. MWP and the interval before treatment were the most important predictors. DCS sequence was included, suggesting that the more often a worker experienced DCS, the more difficult it was to treat the present case.

DISCUSSION

The present series of DCS cases was the largest among the different compressed air tunneling contracts for the construction of the Island Line in Hong Kong. Complete medical records were essential for detailed analysis of the series. The manifestations of DCS among Chinese and Japanese in Hong Kong were described and these generally were similar to those described among Caucasians elsewhere.

The classification of DCS into type I and type II was used and was found to be satisfactory. All cases except one were type I. In the Dartford series, 35 of the 685 cases were type II (9). In comparison, 94.6% of our type I cases had limb pain only. In Elliott and Kindwall's series (10), only 70% had pain. Thus, type II, sickness and manifestations other than pain were relatively uncommon in Hong Kong. The low incidence of type II DCS suggested that the Blackpool Tables were effective in preventing serious sickness. Moreover, in the present contract, there was virtually no decanting and almost all workers underwent proper decompression procedures before leaving the tunnels. As for skin manifestations as a result of decompression, these were easily confused by the workers as heat prickles, which were very prevalent in Hong Kong because of the hot and humid climate. Furthermore, the symptoms were so mild that few workers would report skin problems to the medical center.

In the Dartford series, only the lower limbs were affected in 85% of the 650 type I cases, only the upper limbs in 7%, and both upper and lower limbs in 8% (9). These were almost identical with the corresponding figures of 84.4, 6.9, and 6.9% in the present series. Although Elliott and Kindwall (10) stated that in caisson workers lower limb symptoms were 3–4 times as frequent as those in the upper limbs, the present series showed that lower limb symptoms were 6–7 times as frequent as upper limb symptoms. We have also shown that the right and left sides of the body were equally affected.

The use of oxygen in the treatment of DCS in compressed air workers has not been generally accepted in the United Kingdom, mainly because of fire risk. That is also true in Hong Kong. In the United States, oxygen treatment has been successfully adopted for compressed air construction sites together with stringent safety procedures (11). In Hong Kong, because the British Code was followed, oxygen treatment was carried out only on a trial basis in the present contract. Compared with the usual method, oxygen treatment was faster (average 2.4 h vs. 9.8 h; $P < 0.001$) and all cases had complete symptom relief after one recompression and no recurrence or residual symptoms. Hence, our experience indicated that oxygen treatment could be adopted in a compressed air construction site that primarily followed the British model, provided that stringent regulations and procedures were set up and followed.

Most type I cases were treated by the method of minimum effective pressure treatment as described in the British Code of Practice, with a minor modification. The modification was adopted because our previous experience indicated that it could produce symptom relief faster. This was further confirmed by the results of the present series. The British Code states that pressure as high as 0.7 bar above working pressure is required on only rare occasions to relieve the symptoms. However, 26.2% (205/783) of our cases required more than 1 bar above MWP. This was due to our modification of the recompression procedures. Recurrence of symptoms after the first recompression treatment was found in 9.6% of the cases that were treated successfully with additional recompressions. This figure, taking into account the higher working pressures and longer duration of exposures of our workers, was satisfactory and comparable to the figure of 7.5% reported for the Tyne Road Tunnel series (12) and 7% by Griffiths (13) for cases treated by minimum effective pressure.

Elliott and Kindwall (10) emphasized that reduction of delay between onset of symptoms and the application of recompression was most important to halt the progression of the illness, and Davis and Elliott (11) stated that delay was a powerful factor in diminishing the chance of a full recovery. However, there was no previous study on the extent to which delay could affect the treatment. We have studied in detail and quantified the relationship between delay and the treatment pressures. It was found that pressure of relief was more closely related to the interval between decompression after work and treatment than to delay itself. This finding is not unexpected and can be interpreted as follows. Because the birth and growth of bubbles in the tissues after decompression depend on the interval after decompression, the longer the interval, the bigger the bubbles. A higher pressure is therefore required to reduce the size of the bubble. Delay is less relevant than interval because the former does not include the period before onset of pain, which varies with the pain threshold of the individual.

The interval before treatment is the sum of time of onset of symptoms and delay; persons whose symptoms appeared earlier would have a shorter interval than those whose symptoms were delayed. Because there is no way to predict how soon symptoms will appear, one can only try to reduce the delay after symptoms have appeared. A longer delay would require a higher pressure of relief, at the rate of about 0.04 bar above MWP per hour delay. Multiple regression analysis showed that MWP, interval before treatment, DCS sequence, and duration of exposure were the most important predictors for pressure of relief and highest pressure used. The latter was obviously closely related to MWP because the treatment procedure specified to recompress to MWP or higher. Other variables such as age, nationality, occupation, etc., were found to be unimportant.

It should be emphasized that the present study was not intended to assess the effects of various risk factors or variables associated with the occurrence of DCS. Nevertheless, we have found that several factors which were previously thought to be risk factors for the disease were not important. Only a small proportion of the cases had multiple exposures within a work shift, decanting or decompressions which did not follow prescribed tables. Because of lack of data on the profile of multiple exposures, it was not possible to calculate separately the incidence of bends after single or multiple exposures. However, the small percentage of cases observed here did not suggest multiple exposures are a significant risk factor. In the present contract, decanting was used only on rare or emergency occasions. The design of the lock system in the tunnels was such that workers could not escape through the muck lock without undergoing proper decompression. Histories of upper respiratory infection, injury of affected parts, or excessive use of limbs were uncommon and hence were not important risk factors associated with DCS.

There was also a lack of accurate and specific data on the number of man-decompressions among new starters, absentees, and others for the calculation of DCS rate in these groups so as to study the effect of acclimatization. Other difficulties were the frequent changes in pressure used in the tunnels and the mobility of the workers. Nevertheless, it was known that there were 1549 men who were declared fit for compressed air work during preemployment examinations (6). Since each of them must have been a new starter and assuming that each had 5 decompressions after 1 bar or above during the first five shifts, the number of man-decompressions in new starters was 7745. New starters suffered 140 DCS during the first five shifts. DCS rate in new starters was therefore 1.81%. The number of DCS and man-decompressions in "non-new starters," estimated by deducting those in new starters from the totals in the whole contract, was 653 and 134,395, respectively, excluding decompressions of below 1 bar; DCS rate was 0.49%. The relative risk of DCS in new starters was 3.69. Thus, the risk for the workers was much higher during the initial period of exposures than subsequently, even though the first few shift exposures were usually shorter. These results suggested that acclimatization did reduce the risk of DCS. No data were available on the number of men not following the acclimatization procedures. It was not possible to estimate the DCS rate in absentees returning to work.

Because the incidence of DCS increased with MWP and duration of exposure, these two factors should be taken into account in the study of other risk factors. Furthermore, the study of the personal susceptibility factors such as age, occupation, obesity, experience in compressed air work, etc., must take into account the amount of individual exposure to compressed air and the pressure. To facilitate such analysis, linking various records would be an essential step, but a major undertaking. These include preemployment medical examination records, routine examination records, individual compressed air records, as well as DCS case records. Such linkage has been done and the results of the analysis will be available soon.

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