DECOMPRESSION SICKNESS IN THE SINGAPORE MASS RAPID TRANSIT PROJECT

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ABSTRACT

In the Singapore Mass Rapid Transit Project (MRT), 11 km of underground tunnels were built using compressed air. 1,737 compressed air workers (CAWs) were employed in the project. They underwent 188,538 man decompressions at the various compressed air worksites. 160 CAWs developed Type I decompression sickness (DCS) and 4 developed Type II DCS. This gave an overall incidence of 0.087%. The adoption of strict medical selection, strict adherence to decompression procedures and the provision for acclimatization of newstarters contributed greatly to this low incidence. Prompt treatment of DCS accounted for the low relapse rate. The clinical presentation of DCS is discussed here. Prevention of DCS by worksite environmental and work-practice monitoring are advocated.

Keywords: Decompression sickness, compressed air worker, Mass Rapid Transit

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INTRODUCTION

The use of compressed air in tunneling work on a large scale was seen for the first time in Singapore during the Mass Rapid Transit (MRT) Project. Prior to this, compressed air had been used on a small scale in some local sewage works. Singapore had until then no experience in managing medical problems associated with this type of engineering work.

Compressed air is used to prevent seepage and flooding of tunnels in areas where there is a high water table. Workers exposed to such higher than normal ambient pressure or hyperbaric environment are known as compressed air workers (CAWs). In addition to the usual medical hazards faced by the other construction workers, such as heat, dust, trauma and noise, CAWs face the hazards of decompression sickness (DCS), barotrauma and dysbaric osteonecrosis. These conditions are also seen in deep sea divers and aviators who are exposed to changes in ambient pressure.

In Singapore, the Diving and Hyperbaric Medical Centre (DHMC) of the Republic of Singapore Navy (RSN) has the facilities and experience in the selection of divers and in the management of diving related illnesses such as DCS, barotrauma and dysbaric osteonecrosis. In view of the similarity of medical conditions suffered by divers and CAWs, DHMC was in the best position to help in the MRT Project.

The RSN was approached by the MRT Project Protem Committee in August 1982 to assist in the planning and provision of medical support to the CAWs of the Project. As there were no legislation in the Factories Act pertaining to CAWs, DHMC assisted the Ministry of Labour to work out the appropriate legislation.

The use of compressed air in tunneling is not new. Its first practical use in tunneling was described by Triger in 1839 (1). Since then it has been used in many large scale construction projects. With extensive use of compressed air new clinical entities such as DCS and dysbaric osteonecrosis were described and their pathophysiology studied. The etiological basis of both these conditions is similar. They result from the mechanical and biochemical consequences of nitrogen bubbles in the blood and extravascular tissues. These nitrogen bubbles are produced within the tissues when the drop in ambient pressure exceeds the supersaturation levels of dissolved nitrogen.

In order to prevent supersaturation of nitrogen within the tissues, CAWs are decompressed slowly in accordance to decompression rates set out in decompression tables or schedules. Several tables have been used in the past. Hempleman's Blackpool Tables described in the Compressed Air Construction Industry Research and Information Association (CIRIA) Report 44 of 1972 (2), has been used with a low incidence of DCS in Hong Kong. These tables were employed in the Singapore MRT Project.

DCS presents as an acute condition, usually within hours of decompressing. Dysbaric osteonecrosis is usually seen after several weeks or months following decompression and is considered by many workers as a chronic form of DCS.

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In this article, the authors present their experience in the management of DCS in the MRT Project from 1984 to 1987. Underground railway lines made up 20 of the 65.8 km MRT route. Compressed air was used in the construction of 11 of the 20 km underground stretch. This was necessary due to the soil conditions and a high water table.

MATERIALS AND METHODS

DHMC started medical selection for men applying to work in compressed air in 1984. Pre-employment screening for a total of 2,392 potential compressed air workers were carried out. A total of 1,737 (72.5%) passed. Among the failures, 3 cases were rejected because of Dysbaric Osteonecrosis. All 3 cases had previously worked in compressed air in other parts of the world. Individuals prone or susceptible to DCS were not cleared for CAW. All relevant medical data of the applicants were stored in a microcomputer system.

The population at risk was a cohort of 1,737 workers who were a multinational lot. There were Thai, Korean, Japanese, Chinese, Indian, Malay and Caucasian workers of various age groups. Both shift and non-shift workers were used in the contracts. The non-shift workers included engineers, supervisors, electricians and fitters who entered the tunnel to perform tasks. They spent a variable time in the tunnel and had to be decompressed accordingly.

For ease of reporting and presentation, the cases of DCS were classified into two types after Golding et al (3).

Type I (mild) - symptoms and signs are mild and present as musculoskeletal pain, swelling due to lymphatic obstruction and skin involvement.

Type II (serious) - symptoms and signs are severe and attributable to disorder of the nervous, pulmonary and cardio- vascular system.

Various factors were analyzed including the host characteristics, duration of onset, age, length of exposure, pressure and number of episodes of DCS. Overall incidence, relationship to shift-work and physical environment of the worksite, treatment methods and outcome were also analyzed.

Data on the incidence of Dysbaric Osteonecrosis (DO) was obtained by review of the long bone X-ray reports performed yearly as required by legislation. Factors with regard to pressures of exposure and other host characteristics like obesity, race and number of episodes of DCS were analyzed.

FINDINGS

There were 164 cases of DCS. 160 were of the milder Type I category while 4 were of the more serious Type II category.

Type I DCS

The commonest presentation of Type I DCS in this series was joint pain (154 cases or 96.3%). Eighty-four cases (55%) with monoarticular pain while 70 cases (45%) presented with polyarticular pain. In 76% of the cases, the joints of the lower limb were involved. The knee joint was the commonest join involved (108 cases) followed by the shoulder joint and the elbow joint (Table I).

Table I
Site of Type I Symptoms

SITE	PAIN	SKIN RASHES	LYMPHATIC MANIFESTATIONS
Head	-	1 (macular Rash)	-
Shoulder	19	-	-
Elbow	16	-	-
Wrist	2	-	-
Abdomen	-	2 (Papular Rash)	-
		1 (Marbling Rash)	1
Inguinal Region	-	-	1
Hip	4	-	-
Knee	108	-	-
Lower Leg	-	1 (Itchy, Macular)	-
Ankle	5	-	-
TOTAL	154	5	1

There were 5 (3.1%) cases of cutaneous DCS. Two cases presented with papular rashes over the abdomen. Two cases had macular rashes over the forehead and both shins respectively. One case presented with marbling rash over the abdomen. One case of lymphatic DCS was seen involving the inguinal lymphatics and presenting as swelling of the penile skin (Table II).

The characteristic nature of the join pain noted was that it was deep in nature, aggravated by movement. There was also a limitation of the range of joint movement and altered sensation around the joints.

Table II
Clinical Presentation of Type I DCS

SYMPTOMATOLOGY	NO. OF CASES
Pain :	
Deep Pain	133
Superficial	7
Constant	24
Throbbing	5
Radiation of Pain	3
Limitation of Movement	16
Rashes :	
Erythematous, Papular, Itchy	2
Erythematous, Macular, Itchy	2
Marbling Rash Over Abdomen	1
Lymphatic Swelling	2
Itch	5
Warmth Around Joints	8
Numbness	16

Type II DCS

Table III illustrates the clinical presentation of the 4 Type II cases seen in the MRT project. Three of them were exposed to compressed air for periods exceeding 8 hours. All of them presented within 2 hours of decompression. Case number 4 developed pulmonary DCS following an explosive decompression of the tunnel when a runaway locomotive smashed open the mud-lock door.

Onset of Symptoms

94.5% of the Type I and II cases developed symptoms within 12 hours of decompression (Table IV).

Table IV

Onset of Symptoms

Time	<1Hr	1< 4Hrs	4 <6Hrs	6 <12Hrs	12<24 Hrs	>24 Hrs	Total
No. of DCS Type I	32	68	32	19	1	8	160
No. of DCS Type II	3	1	0	0	0	0	4

Episodes of DCS

Of 1,737 people who worked in compressed air from September 1984 to April 1987, 136 (7.83%) suffered from DCS. Of the 136 CAWs, 114 (83.8%) of them suffered from a single episode of DCS while 22 (16.2%) had two or more episodes of DCS. Table V shows the distribution of DCS episodes amongst the 136 affected. The maximum number of episodes of DCS in any one man was 4.

Table V

No. of Episodes of DCS

No. of Episodes of DCS	1	2	3	4	Total
No. of Men Affected	114	17	4	1	136
% of Men Affected	83.8	12.5	2.9	0.8	100

Incidence and Exposure Pressure and Duration

A total of 188,538 man decompressions were performed in the MRT project. There were 160 cases of mild (Type I) DCS and 4 cases of severe (Type II) DCS, giving the overall incidence of DCS at 0.087%. There were 64059 man decompressions over 1 bar gauge, with 154 cases of DCS, giving an incident rate of 0.256%.

A study of the compressed air exposure time of the 164 cases showed that the majority, 125 cases (76.3%), occurred at exposure times exceeding 8 hours as seen in Table VI.

The incidence of DCS at less than 1 bar exposures was 0.008%. There were 10 cases in 124479 man decompressions. This unexpected finding will be discussed in another paper.

The incidence of DCS at pressures between 1 to 2 bars was 0.211% with 138 cases in 62350 exposures. Between 1-2 bars, for durations less than 4 hours, the results again were significantly lower (p<10-6) than the mean values. At exposure times of greater than 4 hours however, the number of cases of DCS observed were significantly higher than the expected values for the exposures of longer than 4 hours duration (both p values <10-6) (Table VI).

Table III

Clinical Presentation of Type II DCS

CASE NO.	WORKING PR (BAR)	EXPOSURE TIME	ONSET OF FOLLOWING DECOMPRESSION	CLINICAL PRESENTATION	TREATMENT
1 (NS)	1.75	8 hrs 5 mins	1/2 < 1 hr	Pain - left knee and hip joints. Loss of sensation L3,4 bilateral bp 110/70. 2 prev episodes of Type 1 DCS	CIRIA 2
2 (AY)	1.53	8 hrs 23 mins	1/2 < 1 hr	Pain - right knee, Loss of sensation to pinprick over right half of body	CIRIA 2
3 (KP)	1.45	8 hrs 32 mins	1 < 2 hrs	Felt weak and giddy 70 min after leaving Manlock. Noted to be staggering & vomiting but no nystagmus, visual or auditory sympts BP 110/70. Relapsed with giddiness and low BP of 90/50 and vomiting on sitting.	CIRIA 2 and TABLE 6A
4 (IH)	1.4	6 hrs 25 mins	<1/2 hr	Sudden decompression accident Pain - Both knees. Aural barotrauma bilat. Chest pain and dysponea. BP 140/80 Pulse 84	TABLE 6

TABLE VI

Incidence of DCS with pressure and duration of exposure

MAXIMUM WORKING PRESSURE (BARS GAUGE)	DCS TYPE	DECOMPRESSION SICKNESS INCIDENCE IN % (brackets show absolute figures)			DCS INCIDENCE BY TYPE of DCS (%)	TOTAL INCIDENCE (%)
		<4 HOURS	4-8 HOURS	>8 HOURS		
</1 bar	Type I	0.00 (0)	0.00 (0)	0.027(10)	0.008 (10)	0.008%
	Type II	0.00 (0)	0.00 (0)	0.00 (0)	0	-
	No. of Man-Decomp	60976	27080	36423	124479	-
1-2 bars	Type I	0.016 (4)	0.307 (32)	0.359(98)	0.215(134)	0.217%
	Type II	0.00 (0)	0.010 (1)	0.011 (3)	0.006 (4)	-
	No. of Man - Decomp	24596	10423	27331	63250	-
2-3 bars	Type I	0.00 (0)	1.786 (2)	1.724 (14)	0.936(16)	0.936%
	Type II	0.00 (0)	0.00 (0)	0.00 (0)	0.00 (0)	-
	No. of Man - Decomp	785	112	812*	1709	-
TOTAL	Type I	0.005 (4)	0.090 (34)	0.193(122)	0.085	0.087%
	Type II	0	0.003 (1)	0.005(3)	0.002	-

*Exposure time exceeded Blackpool Tables for working pressure.
Extensions to the tables were made to allow safe exit from the tunnels.

The incidence of DCS occurring at pressures greater than 2 bars was 1.978%, with 16 cases in 809 exposures. Above 2 bars pressure, with duration of exposure less than 4 hours, there were no cases of DCS. However, the observed increase in the number of cases of DCS was statistically significant for exposures between 4-8 hours ($p<0.03$) and exposures greater than 8 hours ($p<10-6$) (Table VI).

Incidence of DCS and Heat, Humidity

The incidence of DCS did not appear to correlate significantly with the observed high temperatures and humidity of some tunnels. The highest temperatures were recorded at Contract 105 where temperatures reached a high of 42 degrees Celsius. Most tunnels had relatively high humidity above 80%. At Contracts 107 and 108, there were occasions where humidity reached 100% (Fig 1).

DCS and Obesity

The number of CAWs who were obese were few. However, there were 5 cases of DCS occurring amongst CAWs who had between 24 and 30% body fat and 3 cases of DCS amongst the CAWs who had more than 30% body fat during initial medical clearance (Table VII).

Table VII

DCS and Percentage Body Fat

Percentage of Body Fat (%)	No. of DCS	No. of Man Decompressions	Incidence (%)
< 20	155	180744	0.086
20 -30	6	6655	0.090
> 30	3	1139	0.263

DCS and Occupation

The distribution of cases among the various occupations is shown in Table VIII.

Fig 1

THE MRT PROJECT OF SINGAPORE

Humidity and Temperature Chart

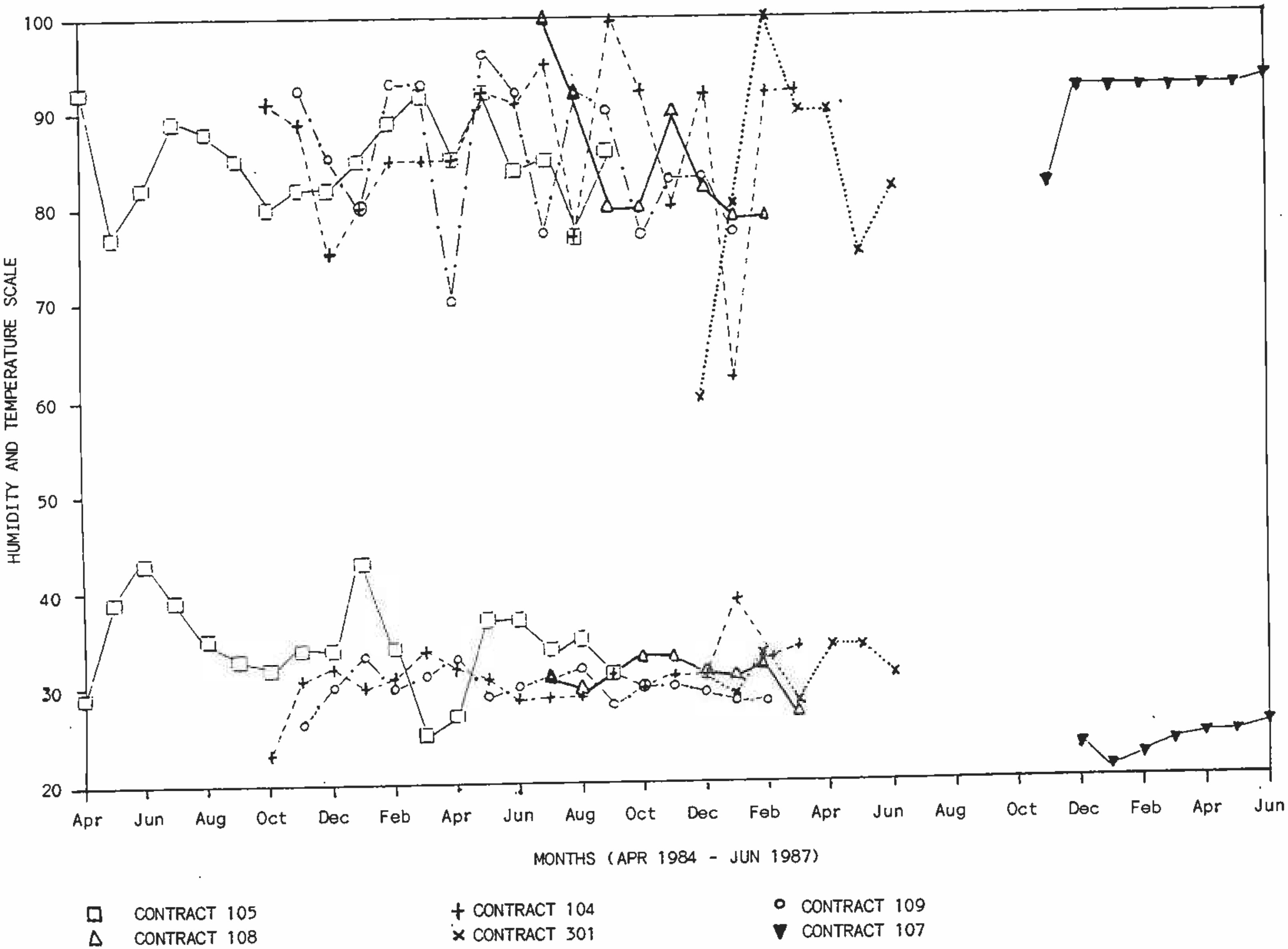

Table VIII

Incidence of DCS by occupation

Occupation	No. of DCS	No of Man Decompression	Incidence (%)
CAW	110	110943	0.099
Engineer	15	51050	0.029
Supervisor	23	12883	0.179
Others	16	13701	0.117
Total	164	188538	Average: 0.087%

Table X

Incidence of DCS by Race

Race	No. of DCS	No. of Man-Decompression	Incidence (%)
Chinese	39	45008	0.0867
Malay	14	15849	0.0883
Indian	34	39064	0.0870
Japanese	20	23035	0.0868
Korean	18	20539	0.0876
Thai	35	40239	0.0870
Caucasian	4	4804	0.0830
Total	164	188538	0.0870

Incidence of DCS by Contracts

The maximum working pressure in the various contracts varied, the lowest being 1.43 bar in Contract 105, and the highest, 2.35 bar in Contract 301. The incidence of DCS by contracts is given in Table IX.

DCS and Shift-Work

The incidence of DCS was evenly distributed among the 3 shifts.

DCS and Race

There appeared to be a slightly higher incidence of DCS occurring in the Indian population as compared to the other races. However, in view of small number of man decompression undertaken by this group of CAWs compared with the other groups, the findings were not significant ($p>1.0$). See Table X. No correlation between DCS incidence and race has been noted in our literature search.

Treatment of DCS

Treatment primarily consisted of recompression with supportive drug therapy. Recompression in most instances were carried out at the medical-locks of the various work-sites. Following the recompression therapy, 100% surface oxygen were administered ensuring no relapse of symptoms.

The CIRIA air therapeutic tables were used in most (73.9%) of the cases. All the medical-locks at the worksites were not equipped with built-in oxygen breathing systems. In resistant and relapsed cases, Workman and Goodman oxygen therapeutic tables were used by bringing into the

Table IX

Incidence of DCS by Contract

Contract	Maximum Pressure (Bar)	No. of DCS			No. of Man Decompression		Incidence of DCS					
							Overall %			Over 1 Bar %		
		Type I	Type II	Total	Total	Above 1 Bar	Type I	Type II	Total	Type I	Type II	Total
104	1.50	36	1	37	79363	39064	0.045	0.001	0.046	0.092	0.002	0.094
105	1.43	3	0	3	27976	937	0.011	0	0.011	0.320	0	0.320
107	1.60	31	0	31	8757	2679	0.354	0	0.354	1.157	0	1.157
108	1.95	26	1	27	19520	6666	0.133	0.005	0.138	0.390	0.015	0.405
109	1.50	28	2	30	38110	5550	0.073	0.005	0.078	0.505	0.036	0.541
301	2.35	36	0	36	14812	9163	0.019	0	0.019	1.746	0.044	1.790
	Total	160	4	164	188538	64059	0.085	0.002	0.087	0.250	0.006	0.256

chamber oxygen breathing apparatus or by transporting the patient to DHMC. Table XI lists the different recompression tables used in the MRT project.

Table XI

Recompression Treatment Used

Recompression Table	Contracts						Total
	104	105	107	108	109	301	
Ciria 1	35	-	26	21	19	14	115
Ciria 2	1	-	1	2	2	-	6
Table 61	-	3	4	3	9	1	20
Table 62	(1)	-	-	(1)	-	15(2)	15(4)
Ciria 1 followed by Table 61	-	-	-	-	-	1	1
Ciria 1 and followed by Table 62	-	-	-	-	-	3	3
Total	37	3	31	27	30	36	160(4)

Note: Numbers in brackets denote cases of Type II DCS
There were 160 cases of Type I and 4 cases of Type II DCS

Of the 164 cases treated, 4 (2.44%) cases relapsed after the first treatment and had to be treated with oxygen. None of the 39 (23.9%) cases treated with oxygen in the first instance, had a relapse.

Dysbaric Osteonecrosis

Of the 1,737 CAWs who were certified fit to work in compressed air, 32 had previous Type B lesions of DO while 11 had other benign findings like bone islands. The CAWs with Type B lestions were allowed to work in compressed air, with limitations of exposure to not more than 2 bars. Follow-up yearly long bone X-rays (LBXR) showed no new cases of DO and those CAWs who had pre-existing DO did not have any further change seen. Six-hundred and forty-three CAWs had exit LBXR done at the end of their contract. None had findings of DO (Table XII).

Table XII

Abnormal Long Bone X-Rays of CAWs In The SMRT Project

Contract	Abnormal Entry LBXR		Abnormal Exit LBXR	
	Type B	Other Ortho. Conditions	Type B	Other Ortho. Conditions
MTF*	1	2	1	2
109	0	0	0	0
108	0	0	0	0
104	0	0	0	0
107	2	2	0	0
MRTC	8	0	3	0
105	2	1	0	0
301	19	6	5	6
Total	32	11	9+	8+

* MTF : MRT Task Force, comprising Firemen from the Singapore o7 3 Fire Service.

\+ Only 643 CAWs had their exit LBXR done. No new cases of DO was seen. The abnormal exit LBXR listed here belonged to those CAWs who had existing lesions noted during the pre-employment examination.

Table XIII

Comparison of Various Compressed Air Contracts

Contract	Period of Compressed Air (mths)	Total No. of CAWS	Maximum Pressure (bar)	No. of Man Decompressions	No. of DCS Cases (Overall)	DCS Incidence Overall	DCS Incidence (> 1 bar)
East River Tunnel N Y 1914 - 21	84	-	3.26	1360000	680	0.05%	-
Howrah Bridge India 1938	6	509	2.72	12400	353	2.8%	-
Lincoln Tunnel N Y 1955 - 56	18	704	2.31	138000	44	0.03%	0.07%
Dartford Tunnel 1957 - 59	24	12000	1.90	122000	685	0.56%	0.97%
Blackwall Tunnel 1960 - 64	44	1536	2.65	81000	863	1.1%	1.09%
Tyne Road Tunnel 1960 - 64	38	650	2.86	44800	711	1.6%	1.74%
Hong Kong Islandline 1982 - 85	36	3966	2.85	443430	2003	0.46%	0.52%
Singapore MRT 1984 - 1987	31	1737	2.35	188538	164	0.07%	0.26%

DISCUSSION

Incidence of DCS in Singapore

The incidence of DCS in the Singapore MRT project was low when compared with compressed air work done elsewhere in the world. (Table XIII).

The main reason for the low incidence is the generally low pressures used. The highest pressures were at Contract 301, which had a maximum tunnel pressure of 2.35 BAR.

From the start, no compromise was made with regard to the selection of men working in compressed air. Workers who were susceptible to DCS were certified unfit or conditionally cleared to work in compressed air. This included the obese (> 24% body fat by skinfold measurement), those with a high incidence of DCS in the past and CAWs with extensive DO. The obese and those with Type B DO were given conditional clearance. They were allowed to work at a limited pressure and for a limited duration only.

The control of proper decompression of the CAWs was also another key element in the low DCS incidence. The manlock and medical-lock attendants were required to attend certification courses conducted by DHMC in conjunction with the National Productivity Board and the Ministry of Labour. In addition all the CAWs were thoroughly briefed on the safety aspects of compressed air work. They were taught the importance of proper decompression and signs and symptoms of early decompression. Some CAWs found tampering with the emergency exhaust valves in the manlocks to release themselves early, were disciplined. The strict control of the decompression procedure paid off and minimised DCS occurring out of negligence.

The legislative framework determined the requirement for the control of the time of exposure. In addition, we believed that a period of acclimatization for newstarters did much to reduce the incidence of DCS. This was incorporated in the legislation for all new CAWs as well as for those who have been away for more than 12 consecutive days. Paton and Walder (4) noted a high incidence of DCS in newly introduced workers, but with acclimatization, the incidence fell. As a result of the regulations, there were very few cases of newstarters who experienced DCS.

The manlock attendants had to abide with the decompression schedules which were laid down in the Factories Act. The control of proper decompression was further ensured by frequent checks of the safely supervisors and the worksite medical officer.

The Blackpool Tables (2), designed by Hempleman, was well tested in the UK and Hong Kong with an overall incidence rate of less than 2%. For exposures less than 1 bar gauge, the Tables call for the CAWs to be decompressed to the surface at a rate not exceeding 0.4 bars/min, without any stops. However, in the Singapore MRT Project, a stop at 0.2 bar for 5 minutes was included in the regulations. This stop was included to reduce the rate of ascent further as we believed that it would have been too risky to ascend immediately to surface, especially after more than 8 hours of exposure.

For CAWs exposed to pressures of more than 1 bar gauge, they had to follow the decompression schedules according to the Blackpool Tables. These Tables required the CAWs to remain at the surface for at least 12 hours in every 24 hours. This was because at the end to decompression, residual nitrogen still remained in the body. This will become accumulative without an adequate rest period at atmospheric pressure.

Multiple entries into the compressed air tunnels were allowed for the supervisors. By law, they were allowed to enter the chambers only 5 times in a 24 hour period at pressures not greater than 2 bars, for not more than half an hour on any one occasion and with a minimum surface interval at normal pressure of more than 1.5 hours.

There were instances where CAWs were exposed to compressed air exceeding the time limits imposed by the Blackpool Tables, either by misinformation or exigencies of work. This posed a problem of decompression for two reasons. One, the Blackpool Tables are designed for a maximum exposure of 8 hours and two, nitrogen saturation of tissues may take as long as 3 to 4 days to complete (5). In order for the CAWs to work at these long hours, extension of the Tables were required and additional stops had to be included as a safety measure. The incidence of DCS was lowered when compared with the incidence following the decompression with the unmodified Blackpool Table. (See Table VI).

In our 164 cases of DCS, 76.2% of them occurred with exposures exceeding 8 hours. A higher incidence of DCS was also noted with increasing pressures (Table 6). This was observed than 1 bar exposures, to 0.936% for exposures between 2-3 bars. With the increase in duration of exposure, there was an overall increase in the DCS incidence.

The higher incidence of DCS noted at the extremes of exposure indicates that far greater risks are associated with long exposures with the use of the Blackpool Tables in spite of the adequacy of control. It is likely that with longer working hours, the workers had absorbed greater amounts of nitrogen and had also been subjected to greater physical stress such as the prolonged use of vibrating tools and lifting heavy loads over long distances in the tunnels. These cumulative factors could result in the development of DCS in some cases. They appeared to be more susceptible to developing DCS than their peers who had been similarly exposed to the same pressures and performed the same type of work.

The overall incidence of the 4 cases of Type II DCS was 0.002% compared with 1 case (0.001%) reported by Lam in the Hong Kong MTR series (6). Three of the Type II cases developed DCS after more than 8 hours exposure at 1.45 bar and above. The fourth case developed DCS as a result of sudden decompression, when the mud-lock doors were smashed open by the runaway rail cars. Three out of the four developed symptoms within 1 hour of decompression, while the last case developed symptoms within 2 hours of decompression.

The incidence of DCS among the obese CAWs was higher than the other CAWs. Nitrogen has been shown to be 5 times more soluble in fat than in lean tissues like muscles. With long exposures, it is expected that there is near saturation of the fatty tissue by nitrogen. This results in a 5 times greater nitrogen load during decompression. Therefore it was not surprising that despite conditionally passing the obese CAWs and allowing them to work for limited time and pressure, this group still showed a higher incidence of DCS.

The supervisor category of personnel had an greater overall incidence of DCS when compared with the other categories of workers (Table VIII). This is related to the nature of their work. They were required to enter and exit from the tunnels up to five times a day, increasing their risk of DCS. The CAWs, in comparison, although were performing heavier work over a longer period of time, exited only once per shift.

The incidence of DCS among the various races were comparable, with no significant difference being noted.

Clinical Presentation

The commonest presentation of Type I DCS in our series was that of joint pain (Table I and II). This occurred in 96.3% of cases with 76% of cases having pain in the lower limbs. Pain was mostly around the joints of the long bones. 84 cases (55%) presented with monoarticular pain while 70 cases (45%) presented with polyarticular pain. 76% had pain in their lower limbs compared with 87.82% in the Hong Kong MTR Project (6). The knee was commonly affected in our series (108 cases - 70.1%), followed by the shoulder joint (19 cases - 12.3%) and the elbow (16 cases - 10.4%).

A detailed analysis of the onset of symptoms revealed that 82.9% of cases had symptoms within 6 hours of decompression, with 95.1% of cases presenting before 24 hours. This is comparable with Lam's HK MTR series (6), with 93.6% presenting within 6 hours.

There were 5 cases of Cutaneous Type I DCS presenting as rashes. These cases proved difficult to diagnose. Two cases presented as swelling of the lymphatics and one who had lymphatic swelling over the inguinal region. These symptoms subsided with recompression therapy. In the HK series, 4 cases had skin mottling, 39 had non-specific symptoms of headache, nausea and vomiting. The other 94.6% (749) cases presented with joint pains.

Treatment

Early recognition of symptoms and prompt treatment were ensured by making it compulsory for CAWs to remain at the worksite for 2 hours following decompression from the tunnel. This probably accounted for the fairly low relapse rate of 2.44% (4 cases). By comparison, 8.2% (64 cases) required a second treatment and 1.4% (11 cases) required third treatment in the HK series. Oxygen recompression therapy was used on 39 cases. This limited use was due to the fact that not all site recompression chambers had built-in breathing systems and over-board dump systems for oxygen.

Adjuvant therapy included fluid replacement. This included Dextran, in addition to Normal Saline and Hartman's Solution. Aspirin was not given to the CAWs because of the possibility of masking the symptoms.

The objective in fluid therapy was to replace depleted blood volume, to restore haemocrit, prevent blood sludging and to improve tissue perfusion. It is common to find patients with acute DCS to have reduced blood volume, and many animal studies have confirmed this finding. Dextran has advantages of restoring intravascular fluid loss by increased vascular permeability during DCS (7), although there are those who are more concerned with the potential of Dextran for creating an acute volume overload and further lung congestion. Our experience has shown us that judicious use of Dextran, especially in the young, robust CAW or fisherman divers with Type I and delayed Type II DCS, reaps benefits of improvement in the symptoms of our patients. We advocate the combined use of fluid therapy consisting of colloids and crytalloids with aspirin, dexamethasone, and recompression therapy in the management of serious cases of DCS.

Prevention

Monitoring and safety checks by medical officers and safety officers at the worksite were conducted regularly to ensure that there were no unsafe work practices. Daily checks of the barographs and the man-lock registers were made to ensure compliance with the prescribed Blackpool Decompression Schedules. They also ensured that workers do not exceed the prescribed working hours for the exposure pressure.

Inspection of man-locks revealed that some of them leaked especially in the last 0.3 bars of decompression. This was due to the poor seals and alignment of the doors. This problem was further compounded as some man-locks were not level. This meant that the workers were rapidly decompressed when the doors suddenly opened. As there was a real danger as this would precipitate DCS amongst the CAWs. Measures were taken by the contractor to modify the chamber doors by including various locking devices. These held the doors shut until decompression was completed. Leaks found at some of the pipings were rectified promptly.

With the high humidity and temperatures in some of the tunnels, the contractors were told to install water coolers within the tunnels to provide the CAWs with ample cool potable water to prevent dehydration.

Accidents

Two major accidents occurred on each at in Contracts 104 (BOCOTRA at Orchard Road) and 105 (TTJV at Novena Station). Runaway rail cars smashed the mud-lock doors of the tunnel causing an explosive decompression. At Contract 105, (tunnel pressure : 1.88 bars), 15 men suffered from aural and sinus barotrauma and 4 had to be admitted and treated at DHMC.

At Contract 104, the tunnel pressure was 1.45 bars gauge when the unsecured railcars rolled backwards and smashed open the mud-lock doors. There were 15 men inside the tunnel while 2 men were working around the mud-lock. The men had been working for 7 1/2 hours. Five men developed symptoms of DCS and the operations centre at DHMC was thrown into full alert. Ambulances were sent to the site and medical personnel were deployed to three recompression chambers to treat the patients simultaneously. One of the workers working around the mud-lock was thrown about 10 metres by the out-rushing of the compressed air. He was evacuated to the hospital with head and body injuries. The number of cases of DCS would have been less (145 instead of 164) if not for these two accidents.

CONCLUSION

Decompression sickness is a preventable condition in compressed air work. The prevention of this illness is to a large extent dependent on the recognition of the hazards involved and in the application of recognized medical and environmental control measures. The DCS incidence of 0.087% in the Singapore experience was low and the medical team involved in the project can look back at the months of compressed air works with much satisfaction. The attention to detail during planning and the adoption of strict medical standards in the selection of men and in safety control ensured that very few cases of DCS occurred out of ignorance or poor compliance with safely regulations. The preventive measures undertaken enabled a fairly good safety record to be achieved.

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