Medical Support for the North East Line Mass Rapid Transit Project by the Republic of Singapore Navy's Naval Medicine Hyperbaric Centre

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ABSTRACT

Naval Medicine Hyperbaric Centre (NMHC) was approached by the Land Transport Authority (LTA) to provide medical support for the North Eastern Line MRT Project. The medical support provided by NMHC focused on providing training, audits and ensuring that safety and health infrastructure were in place even before the commencement of compressed air tunnelling. The extensive use of the EPBM (Earth Pressure Balance Machine) tunnelling machines for the first time in Singapore necessitated a reassessment of the medical support system and paradigm that was based primarily on the older form of tunnelling. The survey results showed that human exposure to compressed air works with the use of EPBM was minimal and no decompression illness was reported. However, there was still a total of 28 cases of barotrauma that were reported which were mainly from the tunnels dug using the open face compressed air tunnelling method. As such, medical providers should still exercise careful planning for the medical support of compressed air works.

Keywords: Underground tunnelling, Compressed air works, Earth Pressure Balance Machine, Decompression Sickness, Barotrauma

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INTRODUCTION

In underground tunnelling works, compressed air is used when there is seepage of water into the tunnel or when there are unstable soil conditions. The compressed air helps to keep out the water and as a column of air to support and maintain the rigidity of the tunnel and to prevent it from collapsing. However, human exposure to compressed air increases the risk of compressed air illness, namely decompression sickness, cerebral air gas embolism and barotrauma.

In the past, from 1984 to 1987, compressed air was used in the construction of 11 of the 20 km underground stretch of the MRT tunnels. It was done using free air tunnelling methods and open face tunnel boring machines whereby all workers behind the face were exposed to compressed air. A total of 188,538 man decompressions were performed in the MRT project. There were 160 cases of mild (Type I) DCS and four cases of severe (Type II) DCS, giving the overall incidence of DCS at 0.087%. Of these cases, 154 resulted as from 64,059 man decompressions over 1 bar gauge[1-5].

The North East Line (NEL) MRT project was started in 1997 and is an extension of the current MRT line. It was radically different from the first MRT project in that it consisted of about 20 km of tunnels and all tunnelling works (except for one contract which had opted to use open face tunnel boring machines) were done using the Earth Pressure Balance Machines (EPBM).

With the EPBM, tunnelling is done using a tunnel-boring machine (TBM) located at the working face of the tunnel. During tunnel boring and as the machine moves forward, the earth/soil (muck) is removed concurrently from the working face by means of a Archimedes screw. As the machine moves forward large C-rings are then placed around the tunnel, which prevent the walls from collapsing, and subsequently grouting is done to make it watertight. With such a system, there is no need for compressed air to be pumped into the tunnel.

Occasionally however, human entry into the tunnel face for maintenance or inspection work is required during which the part of the tunnel in front of the TBM may need to be under compressed air in order to stabilise the walls or to prevent water seepage to facilitate any work done. Having said that, the rest of the tunnel workers behind the TBM are unexposed to compressed air. Therefore with the increase use of the EPBM, it is expected that fewer workers would be exposed to compressed air.

However, as the extent of compressed air works was not known at that point of time and it was the first time that the EPBM was used so extensively in Singapore, it was necessary to assess the extent in which compressed air works would be used and its impact.

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Table I. Exposure to compressed air works.

Date	No. of Man Decompression	Average Working Duration (Time in Working Chamber)	Highest Working Pressure Atmosphere (gauge)	No. of Man Decompression Hours
13.04.99	6	0 hours 46 mins	0.9	0 hours 28 mins
14.12.98	14	2 hours 13 mins	1.2	6 hours 0 mins
15.12.98	24	2 hours 41 mins	1.2	10 hours 57 mins
16.12.98	18	3 hours 6 mins	1.2	9 hours 27 mins
17.12.98	21	2 hours 47 mins	1.2	12 hours 49 mins
18.12.98	8	4 hours 10 mins	1.2	6 hours 39 mins
24.03.99	6	0 hours 55 mins	1.6	1 hours 30 mins

Table II. Results of medical screening.

Cause of Failure During Selection/Annual Re-Certification	
Asthma	6
Abnormal Lung Function Test	1
Middle Ear Problems	4
Hypertension	9
Abnormal ECG	5
Anaemia/Sickle Cell Traits/Thrombocytopenia	7
Inability to Equalise during Pressurisation Test to 10 metres	10
Obesity	5
Colour Blindness (complete and partial)	8
Abnormal Chest X-Ray	3
Abnormal Long Bone X-Ray	2
Multiple Episode of Decompression Sickness in the Past	1

METHOD AND STATISTICS

Naval Medicine Hyperbaric Centre (NMHC) was contracted by Land Transport Authority (LTA) to provide medical support. We also worked closely with the Ministry of Manpower's Occupational Health and Safety Department and with tunnelling contractors to conduct training for manlock attendants, medical lock attendants and private medical practitioners.

It was agreed by LTA that all use of compressed air by the contractors however short the duration would be reported to NMHC as well as MOM. A central registry would be kept to record all cases of compressed air works and the number of man decompression (total number of decompressions done times the number of workers exposed), the average working duration (average number of hours per entry into tunnel face in a single day), the highest working pressure, the number of man decompression hours (number of man decompression times the number of hours spent decompressing). All cases of decompression sickness and barotrauma would be reported to MOM as was required under the factories act.

During periods of compressed air tunnelling, site visits were also conducted to audit the manlock attendant register to ensure that proper application of the decompression tables were carried out as well as to double check on the submissions to MOM and NMHC. We also reviewed the technical and operational status of medical lock, manlock and the occupational health and safety aspect of the worksite for compressed air works. The adequacy of the on site medical support systems and emergency operating procedures were also scrutinised

NMHC would also keep a register of all workers who had gone to NMHC for screening in order to look at the epidemiology of compressed air workers in Singapore. As it was a descriptive study , no statistical analysis was attempted.

RESULTS

Exposure to compressed air works and diseases arising from it

With a total of 16 km of the 20 km of tunnels completed, there had only been seven occasions that necessitated the use of compressed air and a total of 97 man decompression for tunnelling works using the EPBM. (See Table I). This was in contrast to the open face tunnelling with compressed air, where a total of 1,499 man decompression was carried out.

Each time compressed air was used in the EPBM, the number of man decompression (total number of decompressions done times the number of workers exposed) ranged from six to 24. The average working duration (average number of hours per entry into tunnel face in a single day) ranged from 46 minutes to four hours 10 minutes. The highest working pressure experienced in the tunnel face was 1.6 Atmosphere Gauge (ATG). The number of man decompression hours per day (number of man decompression times the number of hours spent decompressing) was between 12 hours 49 minutes and 28 minutes. These data are summarised in Table I. In comparison, for the open face tunnelling with compressed air, the highest working pressure experienced in the tunnel face was 0.8 Atmosphere (gauge). The average duration of exposure per shift was eight hours. The number of man decompression was 1,499.

There were 28 cases of barotrauma injuries sustained in the course of work that were noted by the private practitioners attending to the CAW workers. These were mainly mild sinus and aural barotrauma presenting with pain during pressure changes. They were treated and relieved of symptoms, with no further sequel and no permanent disability. There were no cases of dysbaric osteonecrosis reported.

All the cases except one was from the contract that had elected to use open face tunnelling.

There were no cases of decompression illness during the NEL-MRT project, as compared to Phase I MRT tunnelling (1984-1987) whereby a total of 164 cases were seen. This is attributed to the use of the EPBM whereby much fewer workers were exposed to compressed air as well as the working pressures throughout that was generally not greater than Atmosphere (gauge).

Medical screening

A total of 250 medical screenings were performed at NMHC between 27 April 1998 and 24 November 2000 for compressed air workers, supervisor and engineers from LTA, MOM as well as the various contractors for fitness to work in compressed air. These figures did not include other workers who were screened by private practitioners who were trained and certified by NMHC. A total of 55 failed the initial selection and five failed the annual examinations. (The failures included those who needed further medical review but did not turn up for further subsequently medical screening). See Table II.

DISCUSSION

From 1984 to 1987, when free air tunnelling methods and open face tunnel boring machines were used, large groups of compressed air workers involved in multiple shifts were exposed to pressure. A total of 188,538 man decompressions were performed. There were 160 cases of mild (Type I) DCS and four cases of severe (Type II) DCS, giving the overall incidence of DCS at 0.087% [1-3].

However, with the advent of the Earth Pressure Balance Machines (EPBM), there is no need for routine exposure of workers to compressed air. However, on occasion, human entry into the tunnel face for maintenance or inspection work is required and compressed air may be used. Having said that, the rest of the tunnel workers behind the EPBM are unexposed to compressed air.

Given the number of times compressed air was used in the NEL line and its pressure and duration, it was not surprising that there were no cases of decompression illness. In terms of man decompression, the open face compressed air tunnels accounted for 1,499 man decompression versus 97 in the EPBM tunnels. There were 28 cases of barotrauma which were mainly from the open face compressed air tunnels. Only one case of barotrauma was from the tunnels using the EPBM, however this does not imply that the EPBM is safer with respect to barotrauma. In fact, the sporadic entry of workers into compressed air using EPBM does pose a risk of barotruama as the workers would not be used to entering a pressure environment and equalising their ears on a daily basis.

These findings have implications on the provision of medical support. The current safety and Health regulations and guidelines governing compressed air works were developed in the context of older form of tunnelling methods used in the earlier MRT projects[6]. However with the use of EPBM some of these regulations may need to be reviewed.

Current regulations call for a on-site medical lock when working pressure exceeds 1 bar[6]. However such a close and responsive and therefore costly form of medical support would need to be reviewed as the numbers of workers involved are small and the use of compressed air is unpredictable and sporadic. A newer medical support plan can be better rationalised using a risk assessment approach.

Such a approach can look objectively at the Risk Level taking into account the working pressure and duration expected, number of workers exposed, historical incidence and acceptable risk[7]. Based on such a risk assessment, a step care approach can then be adopted depending on the degree of risk involved.

This can start from simple oxygen first aid and simple transport to the nearest medical lock when there is a minimal risk of exposure. In the event when the expected pressures are high or the periods of exposure long, and the probability of entry and the risk of injury is high, an on-site medical lock can be on standby at all times as required by the regulations. The use of Post Decompression oxygen breathing can also be considered when the risk is moderate (see below).

The other implication of the use of EPBM is in the implementation of recent advances made in decompression, in particular the use of oxygen decompression tables. In Germany and France oxygen decompression is used for the routine decompression of compressed air workers[8,9]. It has been found to be effective in reducing the incidence of Decompression Sickness (DCS) as well as reducing the time taken for decompression[10-14].

However with smaller numbers of compressed air workers in EPBM, economy of scale is not present and the cost to set up such a facility may be disproportionately more than the savings resulting from a decrease in decompression time. This is because there are fewer workers and hence less man-hours spent in decompression time when EPBM is used.

The use of EPBM also impacts on the risk-benefit of using oxygen decompression tables as there have been accidents involving fire and use of oxygen decompression. As such, the industry is generally guarded against the use of oxygen[10,15]. In addition, the risk of fire with oxygen decompression involves not just the compressed air workers but surrounding workers as well. As such the benefit to a few compressed air workers versus the risk to the whole tunelling crew in general needs to be considered.

An alternative to cost of oxygen decompression is the use of post decompression surface oxygen breathing (PDOB). PDOB involves breathing 100% surface oxygen for 20 minutes after decompressing on a standard air decompression table. This was carried out by a Japanese contract and they found that PDOB after an exposure of up to 4 bar for three hours had significantly reduced the rate of DCS as compared to when no oxygen was used. However, the study is not conclusive and further studies will be needed before it efficacy compared to normal air decompression tables can be ascertained[16].

CONCLUSION

The medical support provided by NMHC focused on providing training, audits and ensuring that safety and health infrastructure were in place even before the commencement of compressed air tunnelling. During actual compressed air works, the actual provision of on-site medical support was delegated to private doctors, man lock and medical lock attendant contracted by the various tunnelling companies whilst NMHC provided the on-site audits and quality assurance to ensure that proper safety procedures were in place.

This arrangement allowed NMHC to play the role of a medical consultant and supervisor and to value add to the medical support process whilst at the same time concentrating on its core mission of supporting the Navy.

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