RESULT OF 918 MAN-OXYGEN DECOMPRESSIONS IN A GROUP OF COMPRESSED AIR TUNNEL WORKERS

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ABSTRACT

In a recent Hong Kong compressed air tunnel construction between November 1999 to September 2001, three hundred and one tunnel workers were selected for a compressed air pre-placement medical examination. One hundred and eighty three tunnel workers passed the pre-placement medical examination and underwent 918 man-oxygen decompressions using the French Oxygen Decompression Tables. There were only six cases of ear and one case of tooth barotrauma and no other dysbarisms were recorded. Using French Oxygen Decompression Tables in this compressed air tunnel construction obtained a very promising result. With the advance in tunnelling technology using the Earth Pressure Balanced Tunnel Boring Machine, compressed air workers were less likely to be exposed to barometric hazards. Together with the policy of employing a strict medical selection and using oxygen for decompression, all contribute to the reduction of decompression illness in compressed air tunnel workers.

INTRODUCTION

All current air decompression schedules for caisson and compressed air tunnel workers are inadequate and liable to decompression illness and dysbaric osteonecrosis.[1] Reports on the use of oxygen decompression to reduce decompression illness from France and Germany suggested and founded the basis of today's oxygen decompression procedures for compressed air workers.[2] However, utilization of oxygen decompression for compressed air work as a standardized procedure is not a common place primarily due to the potential risks of using pure oxygen in tunnel.[3]

Tunnel Boring Machines (TBM) are becoming more common as tunnels become longer and tunnelling conditions become more complex. The increase in tunnels constructed in urban environments as well as the demand for longer road and rail tunnels have provided more scope for the Tunnel Boring Machine to be used. In Hong Kong, an 8.7-m-diameter Earth Pressure Balanced Tunnel Boring Machine (EPBTBM) was used to build the 1.78-km-long Kwai-Tsing tunnel during 1999-2001. When the EPBTBM is working in the pressurized mode, it provides continuous support to the tunnel face by balancing earth pressure against the thrust pressure of the machine. The ground excavated by the cutting head is mixed and accumulated under

pressure in the cutting head chamber, and is then extracted by a screw conveyor. The pressure in the cutting head chamber is controlled by balancing the thrust exerted by the machine and the rate of extraction of the excavated material by the screw conveyor. Only during the pressurized mode to replace the cutter head or repair the machine, workers working in the man-lock of the TBM would be exposed to barometric hazards and the risk of decompression illness.

METHODS AND MATERIALS

In Hong Kong, all prospective workers employed in compressed air work must undergo a pre-placement medical examination by an appointed medical doctor to clear any possible contraindications of working in a compressed air environment. Twelve months after the pre-placement medical examination, an updated annual medical examination is also carried to reassess any new problems that arise, which may be incompatible with compressed air work.[4] At the end of the project, a comprehensive exit medical examination is performed on all workers and assesses any complication and residue related to hyperbaric exposure. The total hyperbaric exposures of each worker and working depth were then verified and recorded for this study. Before the commencement of hyperbaric exposure, the appointed medical doctor gave a two-hour training session to each of the compressed air workers on the recognition and safety precautions associated with decompression illness. Workers were also encouraged to report immediately if any symptom developed during or after decompression to the appointed medical doctor. Reassessments of fitness to resume work in compressed air were given to workers who suffered an attack of any dysbarism. During the 918-man hyperbaric exposure, the French Oxygen Decompression Tables were employed and pure oxygen was given at 0.9bar and 0.6bar; decompression stops depended on the working depth and working time with most of the oxygen decompression time spent at 0.6bar. Within the French Oxygen Decompression Tables, there are one to three 5-minute air breaks between every 25 minutes of hyperbaric oxygen breathing during the whole process of decompression.

RESULTS

Three hundred and one workers came for pre-placement examinations, 183 workers passed the examination, and 118 workers were declared unfit (39.2% failure rate). The major failure medical reason was bone or musculoskeletal problems, accounting for 48.3%. Both cardiovascular and respiratory problems accounted for 15.3% each. The total number of man-oxygen decompressions was 918. The mean number of total hyperbaric exposure per worker was five. The maximum working pressure and maximum working time were limited to 3.0bar and 6 hours respectively. The distribution of the worker's nationality was Nepal 69.2 percent, European 19.2 percent, and Chinese 11.6 percent. The mean age of the workers was 31.7 years old.

There were six cases of ear and one case of tooth barotrauma, and no other dysbarism or decompression illness was recorded. Short-term symptoms of oxygen toxicity including mild fingers numbness, head heaviness, and sleepiness were observed in three cases out of 918 man-oxygen decompressions. All these symptoms resolved spontaneously a few hours after the decompression.

DISCUSSION

Bubble formation is the basic pathogenesis of decompression illness and most of its effects relate to tissue hypoxia.[5] It is also well known, since the studies of Paul Bert in 1878, that inhalation of oxygen during decompression has beneficial effects in the prevention of caisson disease and osteonecrosis. These days, its use is widespread among divers but not common in compressed air workers, mainly because of the potential hazards of fire and oxygen toxicity. Cases of decompression illness in compressed air works still reported with air decompression vary from 0.51 to 0.087%.[6,7] In France, oxygen decompression was employed in compressed air work since 1974 and became mandatory in 1992,[1] and in Germany since 1972, becoming mandatory in 1997. In Hong Kong before 1999, the approved decompression method and tables for compressed air work were air compressed and decompressed tables.[8]

Comparing the pattern of disqualifying conditions of the present study with How's and Lam's reports,[6,7] some notable differences can be observed. In Lam's 367 disqualified men, respiratory (42.8%) and cardiovascular (27.5%) problems were two major conditions. While in How's 654 disqualified men, ear (43.6%) problems were the major condition. In the present study of 118 disqualified men, bone or musculoskeletal problems (48.3%) were the major condition while the percentage of disqualified respiratory (15.3%) and cardiovascular (15.3%) problems is comparable with How's report. Concerning respiratory problems, tuberculosis or related diseases were reviewed in only one of the disqualified men. The other 17 workers were disqualified based on their poor spirometry values in abnormal FVC and FEV 1%.[10] In order to minimize the occurrence of dysbaric osteonecrosis, a strict criterion on bone and musculoskeletal selection was adopted in this study, which explained the highest disqualification rate (48.3%) compared to the other two reports. However, the expected hyperbaric exposure with EPBTBM would be greatly reduced and most of the hyperbaric exposures were of short duration. Overweight and over age were not considered as disqualifying conditions in this study. A detailed comparison of the medical reasons for failing pre-placement medical examinations is shown in Table 1.

The potential toxic effects of gases are determined by the alveolar partial pressure of each constituent of the breathing mixture at the pressure of exposure. The maximum pressure used in this tunnel with EPBTBM pressurization was 3.0bar, resulting in 0.6 bar partial pressure of oxygen and just exceeding the potential range of pulmonary oxygen toxicity (Lorrain Smith effect).

During oxygen decompression, oxygen toxicity is marginal (Paul Bert effect) and its effect reduces by adding 5-minute air breaks for every 25 minutes of oxygen breathing and avoids repetitive exposure to limit daily cumulative toxic pulmonary doses of oxygen.

During decompression with oxygen, specific precautions are enforced to all compressed air workers which include hand and face washing to remove all grease and oil; correctly fitting the breathing mask to prevent leakage; keeping oxygen supply valves closed when not in use; forbidding smoking and open fire together with the practice of eliminating sources of spark ignition. Safety control measures on real-time oxygen monitoring to within 23% by volume and correction of deviated values by immediate adjusting ventilation rate do greatly reduce the risk of fire in oxygen decompression.[11]

Table 1. Comparison of Medical Reasons for Failing Pre-placement Medical Examinations

Failure Reason	Hong Kong Kwai Ching Tunnel 1999, %	Singapore subway 1987, %	Hong Kong MTR Island line 1984, %
Cardiovascular problem	15.3	15.6	27.5
Bone or musculoskeletal problem	48.3	1.5	n/a
Ear or hearing problem	11	43.6	7.1
Osteonecrosis	0.8	0.5	3.0
Respiratory or chest problem	15.3	15.6	42.8
Nose and sinus problem	n/a	7.8	n/a
Recompression chamber test	n/a	5.5	n/a
Endocrine problem	3.4	2.1	n/a
Obesity	n/a	n/a	6.3
Over age	n/a	n/a	2.5
Past operation or injury	n/a	n/a	3.8
Others	5.9	7.8	7.1
TOTAL	100	100	100

N/A = no information for comparison

CONCLUSION

In this small sample size study, the results of using French Oxygen Decompression Tables in decompression illness prevention are very promising. Observed side effects of oxygen toxicity were mild and transitory. High-risk workers were excluded during the initial pre-placement medical examination; high expertise of supervising teams and stress on taking precautions in the application of pure oxygen decompression procedure together with the recognition and practice of stringent safety measures contributed to the highly successful rate of decompression illness prevention with oxygen decompression.

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