SPUMS SCIENTIFIC MEETING 2000

MEDICAL SUPPORT FOR THE SYDNEY AIRPORT LINK TUNNEL PROJECT

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Key Words

Decompression illness, fitness to dive, medical conditions and problems, training, treatment, tunnelling.

Abstract

In 1996 a contract was awarded to construct a tunnel connecting Sydney Airport with the rail network. The project involved driving a tunnel through soft ground over a distance of 5.5 km. Medical input involved planning compression and decompression, assessment of fitness to dive, training of workers and lock operators, health monitoring of workers and treatment of related injuries. Oxygen decompression tables were used for the first time in Australia, the UK or US, although they have been successfully employed elsewhere. Oxygen tables improve efficiency and may reduce the risk of decompression illness (DCI).

22 individuals were declared unfit to work in compressed air. Over the course of the project there were 767 entries into raised pressures (interventions), with a median of 4 workers each time, at pressures ranging from 1.75 to 5.02 bar gauge (175 to 502 kPa absolute) with an average time at the cutter head of 3 hours 2 minutes. Compression related problems included 8 cases of decompression illness. The incidence of DCI was one case every 286 man interventions (0.35%) and this problem affected 5.9% of the workers. This incidence compares favourably with that of projects using air decompression .

The combination of the Tunnel Boring Machine (TBM) and oxygen decompression, in a context of vigilant medical supervision, provided a safe working environment. We recommend this approach in the future.

Introduction

In 1996, the Transfield Bouygues Joint Venture (TBJV), an international joint venture between two companies, one Australian and one French, was awarded a contract to construct a railway tunnel connecting Sydney Airport with the existing suburban rail network. In part, the project involved the construction of a tunnel through soft ground (mainly wet sand) over a distance of 5.5 km. (Figure 1). Soft-ground tunnelling is technically difficult, and the successful bid proposed the use of a self-contained tunnel-boring machine (TBM).

The TBM utilises a rotating cutter head and retractable pressure shield designed so that intervention at the cutting face can be achieved for inspection, maintenance and repair when under pressure. Behind the cutting area and access locks, the rest of the TBM is designed to assemble the shaped, interlocking concrete elements that make up the wall of the tunnel. Thus, the TBM leaves a fully-formed tunnel in its wake, ready for fitting out for road or railway use. The cutter head used in Sydney is shown in Figure 2. The development of this technology has been summarised in course materials from the South Bank University, available on-line.[1]

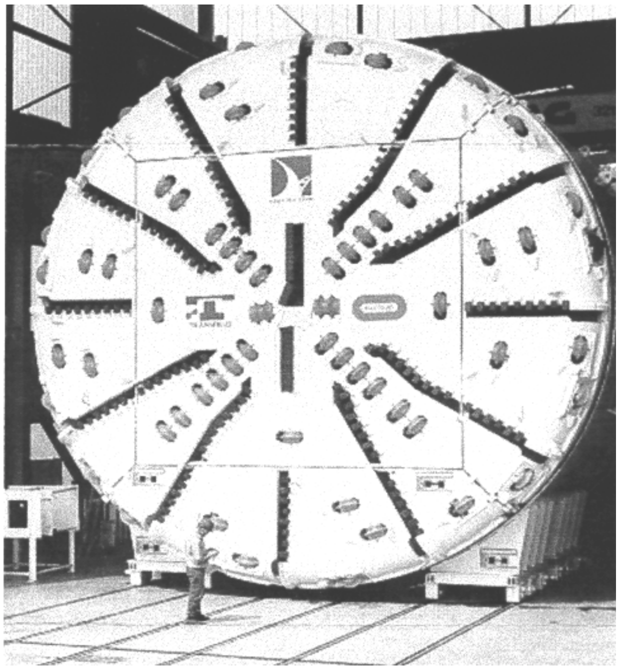

Figure 2. The cutter head and pressure shield after assembly.

While the TBM obviates the need for gangs of workers to spend long periods of time under pressure in order to excavate and build the tunnel, there is nevertheless a requirement for inspection, maintenance and repair at the cutter head under pressure. For this reason, both the local occupational health and safety organisation, Worksafe Authority NSW, and TBJV recognised the need for specialist medical support during tunnelling operations.

Medical support requirements

Operational requirements proposed the employment of approximately 80 manual labourers and engineers capable of working in a compressed air environment at any one time

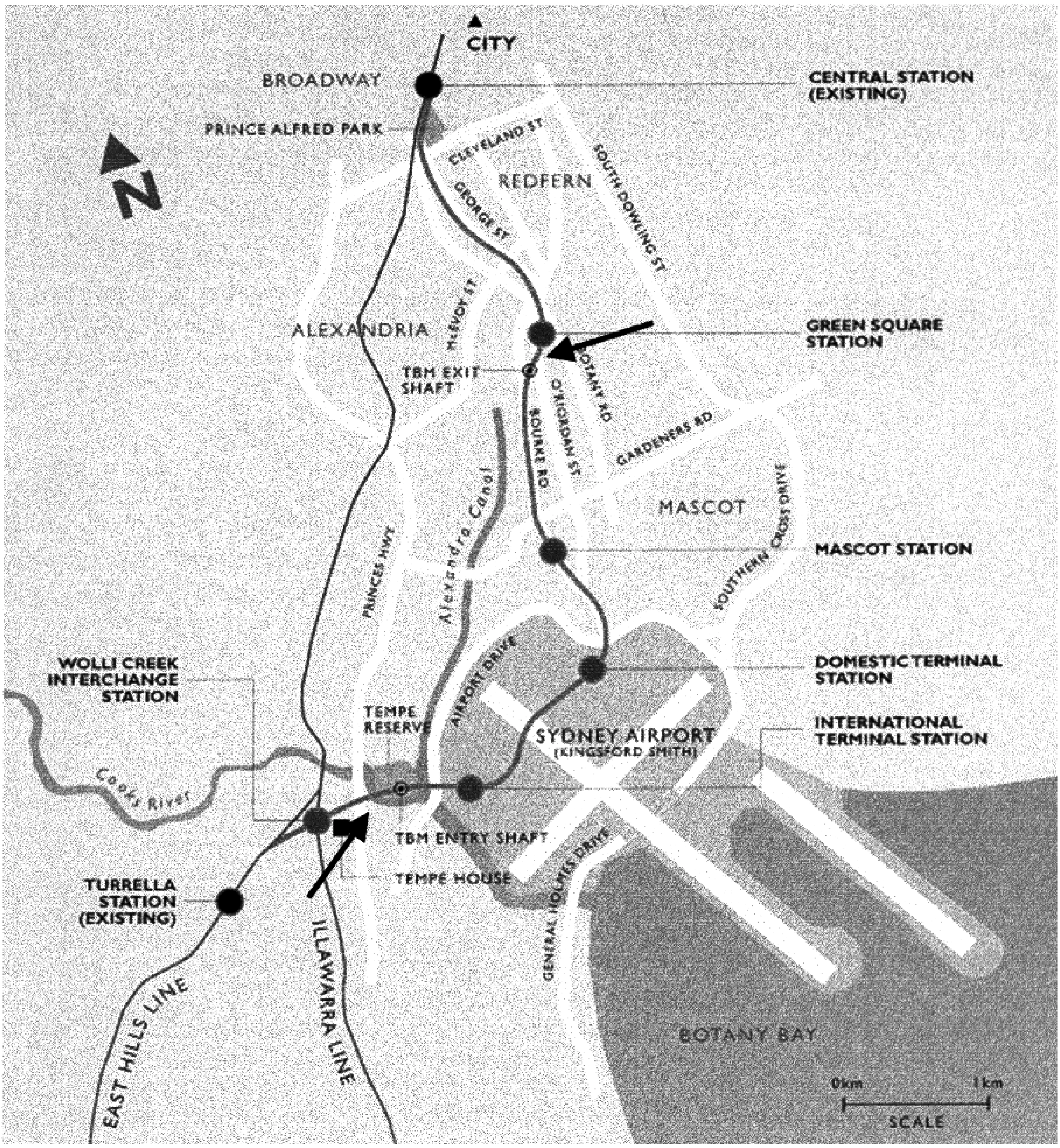

Figure 1. Course of the tunnel. Entry and exit points of TBM are indicated.

over a period of approximately three years. As there was no recent history of similar projects undertaken locally, this involved considerable planning and co-ordination with local ambulance, hospital and medical support. In addition, both workers and their supervising engineers required extensive education and practical training to work appropriately in the compressed air environment. The Prince of Wales Hospital (POWH) Department of Diving and Hyperbaric Medicine (DDHM) was approached early in the planning stages to provide medical support for the project. Wide responsibilities were involved, summarised in Table 1.

PLANNING

DDHM medical staff were required to give specialist medical input to discussions between management and Worksafe NSW. In particular, this discussion concerned the proposed implementation of the French oxygen decompression tables, developed by the French Ministry of Labour in 1992 and discussed by Le Pechon.[2,3] Oxygen had not previously been employed for decompression for compressed air workers in Australia, UK or USA, although the practice is established in Japan, Germany, Denmark and

TABLE 1

SUMMARY OF MEDICAL INVOLVEMENT IN A PROJECT INVOLVING COMPRESSED AIR EXPOSURE OF AN UNTRAINED WORKFORCE

Elements of Medical Support Required

Advise on
- appropriate compression/decompression practices
- appropriate retrieval and hospital facilities required
- specific occupational health risk management

Establish communications for
- effective and timely treatment of workplace injuries

Assess fitness of
- staff required to enter the compressed air environment

Provide
- worker training and education
- lock operator training and education
- medical advice to workers, management and Worksafe NSW
- emergency medical cover during tunnelling operations
- treatment of compression-related problems

Brazil.[3,4] The use of these tables is the subject of review by the Health and Safety Executive (HSE) in the UK. At the time of writing their report was not yet available.[5]

A full discussion of the development of oxygen decompression procedures with regard to compressed air work has been published and Kindwall strongly argues for the introduction of such schedules on the grounds of both safety and efficiency.[6,7]

The use of oxygen breathing periods during decompression facilitates nitrogen elimination and so allows shorter total decompression times. A comparison of air and oxygen decompression schedules demonstrates the significant savings in decompression time for identical workface pressure exposures (Table 2).[2] For example, a period of one hour working at 3.6 bar gauge pressure (460 kPa) will require 150 minutes total decompression time breathing air, compared with a total decompression time of 80 minutes breathing oxygen. Workers undertaking this pressure exposure (intervention) would be required to spend 47% less time in decompression if oxygen was employed.

Work site planning also involved the nature and location of first aid and compression facilities, allowable

TABLE 2

COMPARISON OF WORKING TIMES AND DECOMPRESSION SCHEDULES FOR 3.6 BAR (4.6 ATA) INTERVENTIONS WITH AIR AND OXYGEN DECOMPRESSION.

From Reference 1

AIR DECOMPRESSION SCHEDULE

Working Time	Minutes to first stop	1.5 Bar Air	1.2 Bar Air	0.9 Bar Air	0.6 Bar Air	0.3 Bar Air	Total Decompression	Total Intervention
0 hr 10	11					3	14 min	0 hr 24 min
0 hr 15	11					5	16 min	0 hr 31 min
0 hr 20	10				3	15	28 min	0 hr 48 min
0 hr 25	10				5	20	35 min	1 hr 00 min
0 hr 30	9		3	3	10	25	50 min	1 hr 20 min
0 hr 45	8		10	10	20	40	88 min	2 hr 13 min
l hr 00	7	3	20	20	35	65	140 min	3 hr 30 min

OXYGEN DECOMPRESSION SCHEDULE

Working Time	Mins to first stop	1.5 Bar Air	1.2 Bar Air	0.9 Bar Oxygen	0.6 Bar Oxygen	0.3 Bar Oxygen	Total Decompression	Total Intervention
0 hr 20	10				5	5	20 min	0 hr 40 min
0 hr 25	9			5	5	5	24 min	0 hr 49 min
0 hr 30	9			5	5	10	29 min	0 hr 59 min
0 hr 45	8		3	10	10	15	46 min	1 hr 31 min
1 hr 00	7	3	10	20	20	20	80 min	2 hr 20 min

environmental limits within the access locks and workface, efficient and reliable communication and the minimum time intervals to be mandated before repeat occupational compression.

The planning stage also required liaison with NSW Ambulance and Sydney Aeromedical Retrieval Service with regard to evacuation of serious casualties from compressed air. Particular emphasis was placed on the ability of emergency medical systems within the organisation to safely move an unconscious worker from the tunnel face at pressure, through a period of decompression and to hospital in a timely manner.

ASSESSMENT OF FITNESS TO WORK IN COMPRESSED AIR

Each potential compressed air worker required a detailed examination prior to medical clearance to work in the compressed air environment. This included manual labourers, skilled tradesmen, supervising engineers and safety officers. While detailed standards exist regarding the examination of commercial diving candidates, no specific Australian Standards document exists to protect compressed air workers, although such a document is in an advanced stage of preparation at the time of writing.[8]

We based our examination on existing occupational diving medical standards, modified to allow for the fact these individuals were not planning to be immersed in water during their exposure to high environmental pressure. Routine investigations included an exercise step-test, spirometry, tympanometry, audiometry, chest X-ray and long-bone survey. On satisfactory completion of the medical, the workers were exposed to a short test compression in our main therapeutic chamber in order to learn ear clearing techniques and experience the sensations of compression in a confined space. After successful exposure to pressure, all workers were exposed to a short excursion to 600 kPa at the workplace to further confirm suitability for the planned work. Continued fitness for compressed air work was ensured by regular assessments at six-monthly intervals.

During the course of the project, we examined 162 individuals of whom 142 were passed fit (88%). Of these 136 were actually exposed to compressed air at the workplace. This high pass rate compares to that reported by Lam in Hong Kong of 69% and may reflect an initial questionnaire taken at the workplace to exclude (prior to examination) individuals with active asthma or chronic middle ear conditions.[9] Two hundred and sixty six-monthly reviews were performed. Reasons for failure of the fitness assessment are summarised in Table 3. Eight workers were sent for specialist opinion (3 ENT, 2 cardiac, 1 respiratory, 1 haematology, 1 psychologist) at their own request in order to pursue the ability to work in compressed air, however, all were ultimately rejected for this work environment.

TABLE 3

REASONS FOR CANDIDATES BEING DECLARED UNFIT FOR COMPRESSED AIR WORK
Two workers had multiple problems

Reason Declared Unfit	Numbers
Unable to auto-inflate middle ear on increasing pressure	11
Asthmatic or other pulmonary disorder	5
Psychologically unsuited to chamber environment	2
Miscellaneous	4
Total	**22**

WORKER AND LOCK OPERATOR TRAINING AND EDUCATION

All medically fit workers attended a one week course on the practical implications of work in compressed air. This was conducted by an Australian Diver Accreditation Scheme approved operator (Descend Training Centre, Albury, NSW) and included familiarisation with the compressed air environment, the conduct of safe practice in that environment and the medical and health aspects of compressed air work. As part of this course, DDHM medical staff conducted sessions in common pressure-related illness (in particular the symptoms and signs of middle ear barotrauma (MEBT) and DCI, basic first aid, and the emergency management of DCI.

Thirty five workers, including one female widely thought to be the only female trained as a compressed air tunnel worker in Australia, were trained for a further week as lock operators on the TBM. Medically, they received more detailed instruction on the early diagnosis and management of MEBT and DCI and the mechanisms in place to seek emergency medical help. We relied heavily on instructing these operators to follow a standard diagnostic algorithm and to communicate the findings to the medical officer on duty for such emergencies.

MEDICAL ADVICE TO WORKERS, MANAGEMENT AND WORKSAFE NSW

During the course of the project, DDHM medical staff were available for advice specific to the operation from whatever source. Reports were made on behalf of the workers in relation to the avoidance of dehydration during summer operations, to settle disputes between management and workers with regard to a number of individuals' continued suitability for employment under pressure and to Worksafe NSW to clarify the immediate availability of medical advice, for example. Considerable interest was expressed by the workers in the long-term effects of breathing compressed air on neurological function and bone necrosis, and the medical staff prepared an extensive review on this subject for all parties. No significant disputes were generated, with all problems being resolved by on-site discussions between the relevant parties.

EMERGENCY MEDICAL COVER DURING TUNNELLING OPERATIONS

Medical staff from the DDHM provided continuous cover during the course of the project. The senior tunnelling engineer at the site contacted the duty medical officer whenever manned intervention at the cutter face was underway in order to ensure rapid response in the event of an emergency. Compression facilities were available on-site at the southern exit of the soft ground tunnel with trained personnel immediately available. The compression vessel there was a twin lock, 600 kPa (5 bar gauge) chamber capable of treating one recumbent or four seated patients with an attendant. Further facilities and staff were available on short notice at the POWH, approximately 10 km away. It was anticipated that most therapeutic compression would take place in the hospital.

The period of heightened medical readiness included a "bends watch" period of low activity following the workers' exit from the decompression lock. This watch varied in length according to the exposure profile, being generally between 2 and 4 hours. It was intended to both ensure the workers' proximity to recompression facilities in the immediate post-intervention period and to reduce the incidence of DCI by ensuring no strenuous exercise was taken at this time.

Several potential hazards of work under pressure were identified, including trauma at the cutter head, environmental disturbance (toxic gases, temperature etc), DCI, barotrauma and confinement anxiety. Specific measures were taken to minimise the risk of each.

Medical incidents related to compression work

There was a total of 767 separate episodes of work at pressure (interventions), with a median intervention crew of 4. In total, workers spent 8,134 man-hours at pressure, of which 4,748 hours (58.4%) were spent working at the cutter head and 3,389 hours (41.6%) in the decompression lock. Working pressures varied considerably during the project (Figure 3) and the mean period of intervention was 3 hours 2 minutes at the cutter head. Twin access locks allowed continuous activity (insertion of second crew) and emergency access during decompression of the first crew. There were no significant mechanical failures experienced with regard to compression/decompression equipment.

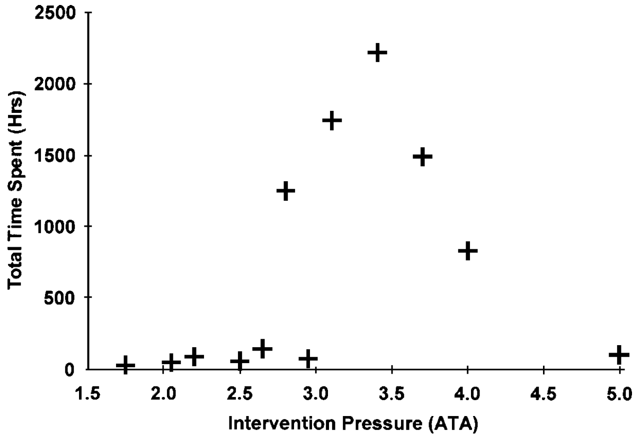

Figure 3. Intervention times and depths (1 ATA = 100 kPa approx.)

TABLE 4

MEDICAL INCIDENTS RELATING TO COMPRESSED AIR WORK DURING THE PROJECT

Medical Incident	Numbers
Middle ear barotraumas requiring medical review	13
Decompression Illness	8
Mechanical injury at cutter head: fractured femur and minor head injury (falling clay), water blast injury, shoulder injury (fall)	4
Significant dehydration requiring active rehydration	5
Incidental finding of significant pathology (lymphoma diagnosed on chest X-Ray)	1
Significant psychological distress	2

A number of medical incidents occurred during the course of the project, including 8 cases of DCI. The details are summarised in Table 4. None of the barotraumatic incidents, mechanical injuries or dehydration episodes resulted in long-term disability and these will not be discussed further. The incidental finding of a lymphoma in one individual resulted in referral to haematology for therapy and he took no further part in the project.

The details of the DCI cases are summarised in Table 5. All involved peripheral joint pain and 4 (50%) also complained of neurological symptoms or exhibited neurological signs. Only Case 3 developed problems while still in the immediate vicinity of the working lock and his symptoms improved markedly on the immediate administration of high flow oxygen as recommended in the standard operating protocols. He was also the only case showing clear cerebral involvement with clouding of consciousness and irrational behaviour. All cases developed

TABLE 5

DECOMPRESSION ILLNESS AS A RESULT OF COMPRESSED AIR WORK EXPOSURE

Case	Intervention to first symptom	Clinical details	Surface oxygen	Therapeutic compressions	Other problems	Outcome
1	14 hrs	Pain L shoulder and knee,	Improved	USN TT6 2.4 x 90 x 1		Full recovery
2	20 hrs	Aching L shoulder, knee, R ankle	Not given	Not treated		Full recovery
3	Immediate	Headache, R arm, knee and lower back pain, confusion	Improved	USN TT6 2.4 x 90 x 1		Full recovery
4	4 hrs	Pain and numbness R hand, lethargy	Improved	USN TT6 2.4 x 90 x 1	Fluid depletion	Full recovery
5	24 hrs	R elbow pain, improves with intervention	Improved	USN TT6 2.4 x 90 x 1	Cervical pain	Full recovery
6	13.5 hrs	Pain R shoulder	Improved	USN TT6 2.4 x 90 x 1		Full recovery
7	6 hrs	Pain L leg	Improved	USN TT6 2.4 x 90 x 1		Full recovery
8	4 hrs	Dizzy, pain, tingling in L arm	Not given	USN TT6		Full recovery

symptoms within the first 24 hours following decompression (mean 10.7 hours) and all those given surface oxygen as first aid therapy improved significantly during that therapy. No cases occurred following compression at less than 250 kPa.

All cases except Case 2 were initially compressed on a standard USN Table 6, with a further oxygen table of 240 kPa for 90 minutes the following day (Case 8 did not return for the second treatment). Case 2 presented to POWH several days after his episode and reported complete resolution of symptoms while resting at home. His history was consistent with DCI and he is included on that basis. All workers returned to light duties 48 hours after the precipitating event and were returned to full active duty, including compressed air fitness, at 2 weeks following injury.

The incidence of DCI during this project was 8/727 (1.1%) of interventions and 8/136 (5.9%) of workers over the three year project. As there were 2,288 individual episodes of compression over this time, the risk of DCI with each individual compression is 0.35%, or an incidence of one case of DCI for every 286 man compressions (number need to compress (NNC) 286). This is similar to the figures for a recent TBM/oxygen decompression project in Kiel, Germany in which 19 cases were reported in approximately 4,000 man compressions (NNC 211) and compares favourably with the previously reported experience with air decompression (Milwaukee, NNC 68; Dartford Tunnel 1957-59, NNC 178; Blackwall Tunnel 1960-64, NNC 94; Tyne Road Tunnel 1960-64, NNC 63, Hong Kong 1975-85, NNC 195).[9-11] [Some figures are as reported by How et al.[12]]

While there is some debate about the possibility of DCI following relatively low pressure exposures, these have been reported.[11,13] In a large project in Singapore using air decompression, for example, the majority of compressions (66%) were at or less than 200 kPa, while the maximum pressure was 335 kPa. One hundred and thirty six of 1,737 workers were treated for DCI (7.8%). The overall reported rate of DCI was 164 cases from 188,538 man-compressions (0.087%, NNC 1,150). Of these, 10 (6%) occurred following an exposure to pressures less than 200 kPa, giving an NNC of 6,406 for these exposures. The authors suggested heavy work, particularly with vibrating tools, repeated exposures and long hours probably contributed to these cases.[12,13]

Reported rates of DCI may be greatly influenced by the consequences to the worker of such a report. Kindwall noted on one project in Milwaukee, for example, that the incidence of DCI was reported as 1.44% based on the numbers requiring therapeutic recompression (the figure quoted above in a different form), while his anonymous reporting system suggested up to 26% of a shift had suggestive symptoms. While previous authors have highlighted a low apparent rate of DCI secondary to poor reporting, our medical team, with the active participation of the management, attempted to generate an environment that encouraged such reporting. On this project, we specifically made it clear that presentation with DCI would not result in loss of income or removal of fitness to continue compressed air work in the absence of dramatic "undeserved" DCI.

No workers exhibited changes suggestive of dysbaric osteonecrosis on skeletal X-ray survey at entry or exit medical. No reports have reached us of the later development of such changes, however this may be due to by the transient nature of the workforce and the absence of further compressed air projects in Australia.

Conclusion

The safe conduct of this tunnel project resulted in an acceptably low incidence of medical problems related to compressed air work. All cases of DCI resolved completely following treatment. The use of TBM technology and oxygen decompression tables are likely to have contributed to this outcome, although the relative contribution of each is not clear.

While there is no substitute for vigilant attention to workplace safety and appropriate medical oversight of compressed air tunnelling, we believe this project to have provided further evidence for the safety and utility of these techniques. Oxygen decompression remains controversial and regulatory authorities in many countries continue to avoid it. Our experience leads us to recommend the use of oxygen decompression tables for suitable future tunnelling projects on the basis of improved worker comfort through shorter recompression times and possibly a reduction in the incidence of decompression illness.

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