Oxygen Decompression may prevent Dysbaric Osteonecrosis in Compressed Air Tunnelling

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Abstract

Dysbaric osteonecrosis (DON) comprises necrotic lesions in the fatty marrow-containing shafts of the long bones as well as the ball and socket joints. The fundamental causes are still in question and the illness remains a significant health hazard. Recent research in animal and human found that intravascular air bubbles triggered coagulation abnormality is an important factor in its pathogenesis. While, genetic factors may also play a role in some potential candidate in DON. [1-3]

The technique of hyperbaric oxygen as oxygen decompression has recently been applied in two compressed air tunnelling projects in Hong Kong during the past few years. As results, two groups of compressed air workers had undergone at least two sets of medical examination with full long bone X-ray examinations. Ninety-seven (n=97) and seventy-six (n=76) of these workers been followed over four to six years respectively. We do not found any evidence of dysbaric osteonecrosis in their radiographs examination. Such a finding may suggest that oxygen decompression not only reduce bubbles load and decompression illness, it may also prevent disabling dysbaric osteonecrosis in future especially when compressed air tunnelling using Tunnel Boring Machine (TBM) with shorter compressed air exposure and swallow working depth.

Introduction

Dysbaric osteonecrosis as it name imply that it is associated with exposure to ambient pressure changes with resulting necrotic lesions in the fatty marrow-containing shafts of the long bones as well as the ball and socket joints of hips and shoulders. The fundamental causes are still in question. Pathological features of both dysbaric and non-dysbaric osteonecrosis are indistinguishable and both types of osteonecrosis are characterized by intramedullary venous stasis, ischemia and necrosis of bone. The clinical features of dysbaric osteonecrosis are being established and its risk factors include exposure to a greater number of decompressions. Compressed air works involve compression and decompression and both are abnormal conditions to human being. In the past, decompression induced bubble formation and its subsequent coagulation abnormalities was considered as a specific and potential risk factor. [4-6] However, the risk of dysbaric osteonecrosis increases with longer shift durations at greater depths [7-9], and decreases with slow rates of compression, suggests that factors unrelated to the decompression phase of the cycle may also be of etiological importance in dysbaric osteonecrosis.

Methods

Subjects:

In Hong Kong, all prospective workers employed in compressed air work must undergo a pre-employment medical examination by an appointed medical doctor to clear any possible contraindications and co-morbidities of working in compressed air environment. Two groups of compressed air workers involved in three tunnel projects during November 1999 to November 2006. As legislative requirement, they underwent three set of comprehensive pre-employment medical examinations including detail X-ray joint profile for all limbs and major joints. The numbers of radiographs taken exceed the recommended level of The British Medical Research Council Decompression Sickness Panel[10]. A total of ten X-ray radiographs were performed on each of these workers. Each set of X-ray films covered shoulders

(4 views), elbows (2 views), hip (2 views) and knees (2 views). All the X-ray films were taken by an accredited diagnostic centre and reviewed by two independent certified radiologists. Any suspicious of radiographically occult osteonecrosis were re-assessed by magnetic resonance image (MRI) scanning. Other risk factors or contraindication for compressed air work have been routinely screening within the pre-employment medical examinations by the author which includes fasting blood sugar (FBS), lipid profile, complete blood picture (CBP), spirometry, resting ECG and urinalysis.

When oxygen decompression method was first introduced to Hong Kong during November 1999, one hundred eighty-three workers passed the pre-employment medical examination. As a result, ninety-seven (97, Group One) and seventy-six (76, Group Two) compressed air workers have been able to follow and recruit over four and six years respectively in this study. These two groups of workers in fact came from the same workers pool which represented fifty-three (53%) and forty-one (41%) percents of all fit workers been first screened in November 1999. However, they also represent the major compressed air workers with at least one compressed air work exposure during this three tunneling. Except being involved in two tunnels using oxygen for decompression, Group Two workers had last set of X-ray films done during November 2006, a recently completed tunnel using air for decompression.

The maximum working pressure and working time were limited to 3.0bar and 6 hours respectively. The distributions of workers nationality among these two groups were mainly Nepal (82 to 75.3%), European (16.5 to 13%) and Chinese (8.2 to 5%) with mean age of 30.2 years old. Detail as in Table1.

A total 918 and 506-man compressed air work exposure carry out in the two tunnels using oxygen for decompression. With a mean compressed air work exposure of 9.5 and 6.6logs per worker per tunnel project. During the compressed air work, the French Oxygen Decompression Tables were employed and pure oxygen was given at 0.9 and 0.6bar; decompression stops depends on the working depth and 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

There were eight cases of ear and one case of tooth barotrauma documented in these three tunnel projects with six cases of ear barotrauma and the only one tooth barotrauma occurred in the first tunnel during November 1999 to March 2002. No other dysbarism or Decompression illness (DCI) occurred in the two tunnels using oxygen for decompression. Two cases of Type I (joint pain only) decompression illness occurred in the last tunnel using air for decompression over the elbow and knee joint. Their sign and symptom response promptly and recovered fully after an urgent on-site recompression treatment using U.S. Navy Recompression Treatment Table 6.

Plain radiography is employed in this study as it is the most simplest and the cheapest method to detect DON lesions. The method has been used for years, although there is a radiation hazard associated with every radiographic examination. Group One has two set of the above mentioned

Table 1 Distribution of worker's nationality among two groups with work class

Racial / Number of workers	Nepal (%)	European (%)	Chinese (%)	Total (%)
Group One	73 (75.3)	16 (16.5)	8 (8.2)	97 (100)
Group Two	62 (82)	10 (13)	4 (5)	76 (100)
Work class	TBM tunneller	Engineer	Welder & TBM tunneller	

Table 2 distribution of X-ray and MRI scan for all recruited samples

Group	No of 1st Set X-ray films	No of 2nd Set X-ray films	No of 3rd Set of X-ray films
Group One	97	97	0
Group Two	76	62*	66
Total X-ray films set	173	159	398
Number of MRI scan	0	1	1
Year of examination	1999	2004	2006

X-ray films while Group Two has three set of the same quantity X-ray films available for analysis. Two set of X-ray films in Group One have at least been taken fours years apart for comparison. Three set of X-ray films in Group Two have the same four and six years apart for comparison. All X-ray films were reviewed and compared with by the author and radiologists. Altogether, there were three hundred ninety-eight (398) set of X-ray films reviewed and all of these films shown to be normal without any evidence of bone necrosis as well as other morphological change. Two suspicious translucent lesions were also excluded by pre-employment MRI scanning. Detail as in Table 2.

Discussion

Various mechanisms, such as bubble embolism, fat embolism, endothelial damage, angiospasm, intravascular coagulation of blood, disturbance of venous flow, increased intraosseous pressure, release of inflammatory mediators including some cytokines, etc. have been proposed regarding the pathognesis of dysbaric osteonecrosis.

Compression-related factors in dysbaric osteonecrosis

During exposure to high ambient pressures, nitrogen gas will dissolve in body tissues in direct proportion to the raised partial pressure, though time of exposure, tissue perfusion and relative solubility of the gas in the tissues are also important. Compressed air workers are usually undertaking some degree of physical activity whilst at maximum pressure. This would have the effect of increasing inert gas uptake in the muscle because of an increased blood flow. It has been long recognized that rapid decompression will cause nitrogen to come out of solution and form bubbles. Intravascular bubbles may obstruct and distend the vascular sinusoids of the long bones fatty bone marrow. The resultant stasis of blood, ischemia and activation of the clotting mechanism resulted in bone death. This provides an explanation for the observed link between dysbaric osteonecrosis and decompression sickness. Walder notes that only 10% of workers with decompression sickness progress to dysbaric osteonecrosis. Conversely, about 25% of those with dysbaric osteonecrosis have never had decompression sickness.[11] Bubbles from decompression are not necessarily sufficient to cause dysbaric osteonecrosis. Thus in certain situations, a 'non-bubble' contributory factor is necessary to produce intramedullary venous stasis and ischemia. The common underlying pathway in dysbaric osteonecrosis is intravascular obstruction from fat embolism or coagulation leading to intramedullary stasis of blood and ischemia. As bubbles cannot be involved in the non-dysbaric cases, it is therefore consistent to propose a contributory 'non bubble' mechanism in dysbaric osteonecrosis as well.

Modern TBM and Dysbaric Osteonecrosis

Tunnel Boring Machines (TBM) becomes commonly use as tunnels becomes longer and tunnelling condition become more complex. Earth Pressure Balanced Tunnel Boring Machine (EPB-TBM) designed to work in both open and closed mode. When the EPB-TBM is working in the closed mode, it will be pressurized to provide a continuous support to the tunnel face by balancing earth pressure against the thrust pressure of the machine. The ground excavated by several excavation discs in head of the machine will be mixed and accumulated under pressure in the cutting head chamber, and is then extracted by a screw conveyor. This TBM require periodic inspection and regular repair of the excavation disc by tunnellers. Only under some soft ground conditions when the TBM is working in closed mode and it is being inspected or repaired, the engineers or tunnellers working in the man-lock of the TBM are required to work in compressed air environment. Such an engineering improvement in tunnelling will definitely reduce the barometric hazards and the risk of decompression illness.[12] However, during this maintenance phase, further proceed of the TBM is impossible and the delays are costly. Besides, a high DCI rates are disadvantageous not only to the individual tunneller but also affect in management perspective in terms of loss of key personnel. This combined with the relative ineffectiveness of air decompression that there is a need to have shorter and effective decompression schedules as well as a method to minimize decompression illness. That is why oxygen decompression and mixed gas techniques are being developed and used worldwide in tunnelling projects.[12] In UK since the introduction of modern TBM in 1993, the total man-exposure to compressed air environment and the reported DCI incidence reduced to within 10 percent of exposure.[13] While the report on DON incidence is lacking suggesting that it may be decreasing as well. The advantage of adding oxygen decompression as report in this study may not necessary truly reflect it actual benefit.

Oxygen Decompression and its limitation

Oxygen decompression" is periods of breathing 100% oxygen through a mask or hood during decompression. This technique has been universally applied in commercial diving industries since the 1960's. It is generally accepted that it substantially reduces the risks of DCI and significantly shortening the decompression time in diving.[14] Using Blackpool Table with oxygen from 0.6bar in human trials of 4 hours exposure at 1.85bar resulted in considerably reduction the number of bubbles detected in the central venous blood.[15], In application, author did reported a zero decompression illness record in 918-man oxygen decompression in 2003.[16] As a result, in1996, HSE has issued an Addendum to the "Work in Compressed Air Regulations 1996 Guidance on Regulations". This Addendum is titled "Guidance on Oxygen Decompression" and effectively notifies disapproval of the use of the Blackpool Air Tables in the United Kingdom. This Addendum brings oxygen decompression into routine use in the United Kingdom above 1.0bar gauge/ 201kPa absolute pressure. It permits air decompression only below 1.0 bar gauge/ 201kPa absolute pressure with significantly increased decompression times in the pressure range 0.81 bar gauge/ 182kPa absolute to 0.95bar gauge/196kPa absolute. This change in the HSE approval of new decompression régimes (other than the air Blackpool Table) became effective on the 17th September 2001.[17]

One of the problems of using oxygen on decompression is that, should it become necessary to treat decompression illness, the treatment itself incurs an extra oxygen load. A standard USN6 decompression treatment table has 648 unit pulmonary oxygen toxic doses (UPTD). When the maximum daily working time of compressed air work at 6 hours in 3.0bar, each of the workers may have the total UPTD exceed 1500 units and resulted in about 10% decrement in vital capacity. The two tunnels using French Oxygen Decompression Tables adopted a standardized compression and decompression rate at 0.3bar/min with air break of 25:5 minutes cycle as a common issue for reducing oxygen toxicity. In clinical hyperbaric oxygen treatment setting, employing well designed and comfortable oxygen breathing mask and hood to deliver pure oxygen is much easier then in compressed air work environment especially when the TBM man-lock is small, hot and humid. In order to reduce the risk of fire, the control measure of oxygen partial pressure inside the man-lock to be within 23 percent is also a difficult but achievable task. During decompression with oxygen, specific precautions are enforced to all compressed air workers which include hand and face cleaning to remove grease and oil; correctly fitting the oxygen 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 source of spark ignition.

Conclusion

Although current result is very promising and seems to be the first of this kind of report on oxygen decompression with reduction in dysbaric osteonecrosis, it is still limited by the small man-exposure and sample size. Further study with larger tunneling project involves greater number of man-oxygen decompression exposure is necessary to validate our result and make it as a good recommendation for its general application as routine for compressed air tunneling.

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