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Arterial gas embolism: a review of cases at Prince of Wales Hospital, Sydney, 1996 to 2006

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SUMMARY

Arterial gas embolism may occur as a complication of diving or certain medical procedures. Although relatively rare, the consequences may be disastrous. Recent articles in the critical care literature suggest the non-hyperbaric medical community may not be aware of the role for hyperbaric oxygen therapy in non-diving related gas embolism. This review is part of an Australian appraisal of experience in the management of arterial gas embolism over the last 10 years.

We identified all patients referred to Prince of Wales Hospital Department of Diving and Hyperbaric Medicine with a diagnosis of arterial gas embolism from 1996 to 2006. Twenty-six patient records met our selection criteria, eight iatrogenic and 18 diving related. All patients were treated initially with a 280 kPa compression schedule. At discharge six patients were left with residual symptoms. Four were left with minor symptoms that did not significantly impact quality of life. Two remained severely affected with major neurological injury. Both had non-diving-related arterial gas embolism.

There was a good outcome in the majority of patients who presented with arterial gas embolism and were treated with compression.

Key Words: arterial gas embolism, non-diving, management

Arterial gas embolism (AGE) may occur as a complication of diving, in association with accidents involving compressed gas, or be iatrogenic, for example following cardiopulmonary bypass, lung biopsy or neurosurgical procedures[1-4]. Gas may be introduced directly into the arterial tree or via the venous system and a right-to-left cardiac or intrapulmonary shunt. The potential sequelae include death and permanent neurological injury. In diving-related AGE, the accepted definitive therapy is compression with oxygen or helium/oxygen mixtures as rapidly as possible[5].

Recent articles in the critical care literature imply that the role of hyperbaric oxygen therapy (HBOT) is at best a secondary consideration in non-diving related gas embolism, when it is considered at all[2,3,6]. This has prompted the hyperbaric community to collect data from non-diving related AGE cases nationally.

This report reviews data relating to patients who presented with a diagnosis of diving or non-diving related AGE to the Prince of Wales Hospital Department of Diving and Hyperbaric Medicine over a 10-year period from 1996.

SUBJECTS AND METHODS

The review was approved by the ethics committee of the Prince of Wales Hospital (Sydney, N.S.W., Australia). All information was gathered according to NHMRC guidelines. A database search at the Prince of Wales Hospital Department of Diving and Hyperbaric Medicine was made for all patients referred with a possible diagnosis of AGE from April 1996 to April 2006. Criteria for inclusion were patients who had a diagnosis of AGE either by the treating physician or, on review of notes, had aetiology, signs and symptoms consistent with AGE. Database entries that were ambiguous or incomplete were further investigated. All notes were retrieved and examined to determine nature of injury, delay to presentation, treatment administered and outcome.

RESULTS

Twenty-six patient records met our criteria, of which 18 (10 male) presented with diving related

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AGE and eight (four male) with non-diving related AGE. In the diving related group average age was 33 years (range of 17 to 63) while in the non-diving related group the average age was 60 years (range 43 to 80). Of the diving-related incidents, 12 followed rapid ascent as a result of inexperience or loss of air; these are presumed to have suffered pulmonary barotrauma with entrainment of air into the pulmonary veins. Four had a significant patent foramen ovale confirmed on transoesophageal echocardiography and were presumed to have suffered right to left intracardiac shunt of bubbles. Another two were suspected of having patent foramen ovale on clinical history but this was not subsequently confirmed by transoesophageal echocardiography.

Of the eight non-diving related patients, two were transferred intubated and ventilated directly from the cardiothoracic operating theatres following complications of cardiopulmonary bypass with significant air noted in the aortic cannula during coronary artery bypass grafting. One had evidence of coronary artery embolisation with profound hypotension and arrhythmia. Two were referred from cardiothoracic intensive care when noted to have major neurological deficits following valve replacement surgery—one aortic valve replacement, one mitral valve replacement. Two patients were transferred with neurological abnormality following fine needle aspiration biopsy of the lung and one directly from the operating theatre following excision of meningioma.

The remaining patient had been participating in an emergency decompression exercise with the Royal Australian Airforce when he developed sudden onset of presyncope, visual loss and ataxia.

Symptoms and signs were variable. Twenty patients had objective neurological signs on admission. Three were intubated and ventilated and therefore could not be assessed and three presented with constitutional and subjective neurological symptoms only. Table 1 summarises the major clinical features on arrival at the Prince of Wales Hospital Department of Diving and Hyperbaric Medicine.

The interval from event to treatment in divers ranged from two to 44 hours and in non-divers 45 minutes to 14 hours. All patients were compressed initially to 280 kPa on a Royal Navy 62 (RN62) compression schedule lasting four hours and 45 minutes. Four patients had one or more extensions at 280 kPa where the treatment was prolonged by at least one further 20 minute period on oxygen—three divers with paraplegia or quadriplegia and a non-diving patient who had

TABLE 1
Symptoms on presentation

Symptoms/signs	Diver	Non-diver
Headache	7	1
Paraesthesia	4	
Syncope/presyncope	6	
Paraplegia/quadriplegia	6	1
Hemiplegia		2
Cranial nerve signs	3	2
Bladder /bowel	3	
Chest Pain	3	
Ataxia/vertigo	3	1
Confusion		1
Cardiac arrest	1	
Anaesthetised		2

ongoing hemianopia and vertigo. One of the divers with paraplegia was transferred to a nearby facility for a COMEX 30 compression table after a poor response to initial compression at 280 kPa. This table involves the administration of 50% helium and 50% oxygen at a pressure of 405 kPa. His condition did not change significantly during this treatment but subsequently improved with further compressions at 280 kPa.

The average number of treatments for all divers was 3.6 (range one to 14) and divers with motor weakness received more treatments, average 5.25 (range two to 14). Average number of treatments for non-diving patients was 2.8 (range one to five).

Lignocaine was administered to five of 18 (28%) divers and five of eight (63%) non-divers. The use of lignocaine was not statistically associated with an increased chance of full recovery (P=0.06, Fisher's exact test). Other adjunctive therapies included intravenous fluids and non-steroidal anti-inflammatory drugs.

Twenty-two patients had significant objective and subjective improvement in neurological symptoms and signs after one RN 62 treatment. Of the six other patients, three were asymptomatic after emergence from anaesthesia, one improved slowly over the next few treatments and two were left with significant neurological sequelae.

Complete resolution of symptoms and signs occurred in 15 out of 18 (83%) divers and five out of eight (62.5%) non-divers (P=0.3). Three out of 18 (17%) divers were left with minor symptoms that did not significantly impact on quality of life. These included urinary hesitancy, minor leg weakness and slightly altered lower limb sensation. No diver was

left with major neurological sequelae. However, two out of eight (25%) non-divers remained significantly affected with major neurological injury (P=0.09). One patient improved initially with compression but then deteriorated and a later computerised tomography (CT) scan confirmed an ischaemic stroke. The second patient developed paraplegia following fine needle aspiration biopsy and did not demonstrate any response to compression. Treatment was suspended after three HBOT sessions due to diagnosis of small cell lung carcinoma.

Neurological imaging was performed on 16 patients, CT scan of the brain on 10 patients and magnetic resonance imaging (MRI) of the brain and spinal cord on seven (one patient had both). Only one CT scan of the brain demonstrated abnormality (ischaemic stroke) while one MRI in a paraplegic diver demonstrated spinal changes consistent with inflammation or ischaemia. The remainder of the investigations detected no abnormality.

There was no significant relationship between a delay to treatment (more than six hours) and residual abnormality (P=0.37 with χ^2). However, paraplegia or hemiparesis on admission was associated with worse outcome (P=0.002). Even so, all divers did well in the long-term.

DISCUSSION

Data on the natural history, morbidity and mortality of air embolism in humans is scarce. Randomised controlled studies for therapy are also few and focused on pre-emptive intervention during cardiopulmonary bypass, in particular lignocaine[7,8]. Mitchell's study in patients undergoing aortic valve replacement demonstrated significant benefit in regard to cognitive outcome in patients who received lignocaine for 48 hours from the commencement of surgery[7]. A number of anecdotal cases in the hyperbaric community have suggested improvement in neurological function following the administration of lignocaine to patients with severe neurological signs who are not responding adequately to HBOT alone. However, our data did not demonstrate the benefit of lignocaine. This may be due to late administration to patients who were more severely affected and inadequate power due to small sample size in a retrospective case series.

Case reports and retrospective studies in humans suffering AGE have suggested that HBOT is the treatment of choice for this potentially devastating complication[5,9,10]. Although there are no randomised controlled trials of HBOT in AGE, the pathophysiology, data from human series compared to historical controls and animal experiments all support the use of HBOT in this situation. There are no randomised data to support any alternative treatment strategies[4,5,9,10,12-14].

The mechanism of injury from bubbles has been extensively investigated. The injection of 0.05 to 1.0 ml/kg air into the cerebral circulation is sufficient to cause changes in brain function in several animal models. Most bubbles will be rapidly shunted through the cerebral circulation by the arterial perfusion pressure[15,16]. If a sufficient volume of air reaches the cerebral circulation it may physically obstruct blood flow at the arterioles causing ischaemia and distal hypoxia[17].

Small volumes passing through the cerebral circulation may not cause significant ischaemia, but are not benign. A shower of bubbles increases global cerebral bloodflow in the short-term although localised areas of decreased perfusion also exist[15].

Hyperaemia and increased diffusion of water across the blood brain barrier are likely to cause cerebral oedema and the increase in intracerebral pressure that accompanies AGE[1,5,9,15,16].

Interaction of gas with blood components results in activation of coagulation and complement pathways while contact with the endothelial interface induces leucocyte activation, chemotaxis and vascular changes[1,9]. Microvascular obstruction may follow and result in secondary ischaemic injury. These changes are responsible for the typical clinical scenario.

HBOT may improve the situation in a number of ways. First, oxygen breathing at pressure reduces bubble size through Boyle's Law and denitrogenation of the tissues down a steep tension gradient promotes bubble nitrogen resorption and excretion. The rapid reduction in bubble size may also directly limit endothelial damage and secondary effects. Perhaps of more clinical relevance, HBOT has also been shown to reduce leucocyte activation through inhibition of ß2 integrins and intercellular adhesion molecule synthetase. Improved oxygen tension in ischaemic tissues may normalise membrane function and assist resolution of cerebral oedema[18,19]. As a consequence of these changes the intracerebral pressure is reduced and there is improvement in brain metabolism[20].

Outcome in patients with clinically acquired AGE is not as favourable as that in patients with diving-related injury[9]. Possible reasons are greater bubble load and increased co-morbidity prior to the event. Despite this, the likelihood of severe sequelae in both groups is low. A recent summary of all studies available

on air embolism in a clinical or diving population undergoing HBOT supports our findings[9]. In our group the majority of patients, even with objective neurological signs, had marked improvement after one HBOT and almost complete recovery with minimal residual signs by the completion of therapy. Moon and Gorman summarised 27 case series with gas embolism. Of 729 patients, 441 were treated with HBOT and 346 (78%) recovered fully, 45 had residual deficits and 20 died. Of the 288 patients who did not receive HBOT 74 (26%) recovered fully, 63 had residual and 151 died. Moon and Gorman concluded that this demonstrated the benefit of HBOT[21].

There is a general conclusion from expert opinion in the literature that results are improved when delay to compression is short[5]. Our data did not support this conclusion and nor do case reports where delay to treatment as long as 48 hours has still resulted in favourable outcome[11,12]. However, our numbers are small and we believe it remains prudent that patients suffering significant neurological sequelae from AGE should be treated with HBOT as soon as it is recognised and practical.

As expected, neuroimaging did not seem to be helpful in the majority of our cases. This is consistent with previous reports. Duke Medical Centre reviewed neuroimaging from patients with acute neurological decompression illness. CT scan abnormalities relevant to the clinical picture were found in four out of 17 scans. Abnormal MRI findings were present in 17 out of 46 scans; 11 of those were small T2 abnormalities. The conclusion was that MRI was insensitive to abnormalities and could not be recommended as a routine study in these patients[22].

Microembolism during cardiopulmonary bypass is common but macroembolism is rare, with an incidence less than 0.1%[23]. In the vast majority of cases signs and symptoms are subtle and resolve rapidly. Cardiothoracic patients in our series were referred only when bubble load was noted macroscopically and expected to have significant effects, or when objective neurological signs developed postoperatively. Results from HBOT were favourable with three out of four patients having excellent recovery. The fourth patient slowly improved despite evidence of infarction on CT but was left with significant residual loss.

CONCLUSION

Although uncommon, AGE may have devastating long-lasting effects. HBOT is associated with rapid and significant improvement in the majority of patients who suffer from this condition. Early recognition with referral to a centre for HBOT should be considered as part of initial management. The literature suggests that even late referral for HBOT may result in significant improvement in symptoms and signs and is worthwhile. Criteria for referral should include macroscopic evidence of embolisation, such as during cardiopulmonary bypass, and in any patient with unexpected neurological abnormality following a procedure at risk.

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