PROSPECTIVE STUDY OF AIR EMBOLISM

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SUMMARY

Air embolism is a potentially fatal complication. A prospective study of air embolism during neurosurgery in the sitting position was carried out. The overall incidence of air embolism was 22.2 per cent in all patients operated on in the sitting position and 40 per cent in cases of occipital craniectomy. Almost all episodes occurred in the early stage of the operation; however, air embolism occurred also in the late stage of the operation. The signs used for diagnosis are described. Decrease of end-expiratory carbon dioxide concentration was an early diagnostic sign of air embolism. The main treatment in 18 episodes consisted of aspiration of air through the central venous pressure catheter and discontinuation of nitrous oxide. Three cases are reported in detail.

The sitting position is preferred by many neurosurgeons for operations on the cervical spinal column, posterior fossa and Gasserian ganglion, for ventriculography and bilateral burr holes because of improved venous drainage and better exposure (Michenfelder, Gronert and Rehder, 1969; Leivers, Spilsbury and Young, 1971). The anaesthetist also recognizes advantages when an anaesthetized patient is placed in the sitting position. He has better access to the chest wall for monitoring purposes or therapeutic needs; ventilation can be performed better than in the prone position; arm vessels are more accessible and urinary catheter obstruction which upsets fluid balance calculations is less likely to occur (Martin, 1970). On the other hand, this position has many disadvantages. The greatest problem to the anaesthetist is perhaps the risk of air embolism (Hunter, 1962; Tisovec and Hamilton, 1967; Michenfelder, Gronert and Rehder, 1969).

In June 1970, we experienced a case of massive venous air embolism during the sitting position in neurosurgery, which was treated successfully by aspiration of air through the central venous pressure catheter. Since this experience, the author has surveyed the occurrence of air embolism prospectively.

MATERIAL AND METHODS

During a 9-month period (July 1970 to March 1971), 36 neurosurgical procedures were performed in the sitting position (occipital craniectomy 20, cervical laminectomy 3, V-A shunt operation 13). In all cases, general anaesthesia was induced with thiopentone followed by suxamethonium for endotracheal intubation. General anaesthesia was maintained with nitrous oxide, oxygen and halothane, or with oxygen and halothane. Ventilation was assisted or controlled manually.

In most cases, continuous direct arterial blood pressure, end-expiratory carbon dioxide concentration (infra-red CO₂ analyser, Godart type CG119), and e.c.g. were monitored and recorded simultaneously. An oesophageal stethoscope was used. A catheter was inserted through an antecubital vein for measurement of central venous pressure and the location of the catheter tip was confirmed by chest radiography. Blood-gas analysis was performed in 9 cases of 36 (4 of 8 air embolism cases) with the Instrumentation Laboratory meter, model 113.

Air embolism was suspected when "mill-wheel" murmur, systolic murmur, cardiac arrhythmias, hypotension, lowered end-expiratory carbon dioxide concentration, tachycardia, respiratory change, and/or elevated central venous pressure were observed, and suction of air through the central venous pressure catheter confirmed the diagnosis.

RESULTS

The incidence of air embolism was 22.2% (8 of 36 cases) of all cases operated on in the sitting position and 40% (8 of 20 cases) in occipital craniectomies. Air embolism occurred on 18 occasions and more than twice in 4 cases (50%). Episodes were noted between 15 and 435 min after the operation was started. Ventilation was assisted

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during 9 and controlled in 9 episodes of air embolism. The signs, symptoms, and treatment were as follows.

The murmur was heard in 11 of the 14 episodes by the use of an oesophageal stethoscope. In the other 4 episodes auscultation of the heart sound was imperfect because of the noise caused by the suction pump of the carbon dioxide analyser. The nature of the murmur was recognized as a "mill-wheel" in 6 episodes (55%) and as a "systolic" murmur in 5 episodes (45%).

Arterial pressure did not change in 2 episodes. Hypotension was moderate (<25% decrease) in 2 episodes and marked (>25% decrease) in 14 episodes. In 2 episodes, arterial pressure fell almost to zero.

Respiratory change was recognized in 10 of 16 episodes (61%) (e.g. coughing, gasping, marked tachypnoea, or sudden appearance of spontaneous respiration in controlled respiration). In the other 2 episodes, we do not know whether respiratory change was present or not.

Cardiac arrhythmia was recognized in 8 of 13 episodes and mostly took the form of ventricular ectopic beats. Recording of the electrocardiogram was faulty in the other 5 episodes.

A reduction of end-expiratory carbon dioxide concentration was detected in 12 episodes. Unfortunately, the infra-red carbon dioxide analyser was not used when the other 6 episodes of air embolism occurred. An increase of central venous pressure was observed in Case 1 (fig. 1) and Case 3 (fig. 4).

Though some authors (Bethune and Brechner, 1968; Brechner and Bethune, 1971) have reported a rise in Pa\textsubscript{O\textsubscript{2}} in dogs, no uniform change of Pa\textsubscript{CO\textsubscript{2}} was seen in our study.

The 18 episodes of the present series were treated mainly by aspiration of air (on 13 of 18 occasions) and discontinuation of nitrous oxide (on 11 occasions). Other minor therapeutic methods were position change (on 4 occasions), administration of vasopressor (on 2 occasions), and continuous positive pressure ventilation (on 2 occasions).

The volume of air aspirated ranged from 1 to 1003 ml.

**DISCUSSION**

The incidence has been reported as 15% in a series of 34 patients (Marshall, 1965) and as 8% in 37 cases (Hunter, 1962) performed in the sitting position. Michenfelder and associates reported the incidence as 2.6% (1966) and 4.1% (1969) in posterior fossa operations. A high incidence of air embolism was noted in the present study, probably because it was done prospectively and monitoring equipment was set up specifically for detection of air embolism. This complication can also occur without any change in vital signs (fig. 1). A higher incidence had been reported when the Doppler ultrasonic detector was used (Maroon, Edmonds-Seal and Campbell, 1969; Michenfelder, Miller and Gronert, 1972). In a critical report, Michenfelder, Miller and Gronert (1972) question the diagnostic value of the Doppler device.

![Graph showing blood pressure and pulse rate](https://academic.oup.com/bja/article-abstract/44/12/1306/268534)

**FIG. 1.** Record during operation for removal of acoustic neurinoma in a 42-year-old female. Air embolism was suspected only by the decrease of end-expiratory carbon dioxide concentration and the increase of c.v.p., and was confirmed by aspiration of intravascular air. Note absence of alteration in blood pressure and pulse rate.

In this series, air embolism occurred even at a late stage of the operation.

Hunter (1962) reported that the incidence is increased by the use of controlled respiration. On the other hand, Michenfelder, Gronert and Rehder (1969) reported the opposite result. From the present study, it appears that the occurrence of air embolism is not closely related to the method of ventilation.

Mikenfelder and associates had reported the incidence of "mill-wheel" murmur as 27% (1966).
and 11% (1969). In this series, "mill-wheel" murmur was audible in 55%.

Hypotension was marked in 78% of cases but no death occurred in this series. It is emphasized that direct arterial pressure monitoring is a safeguard during operation in the sitting position.

Sudden onset of laboured spontaneous respiration during controlled respiration, which had been reported by others (Martin, 1968; Michenfelder et al., 1969), was also noted.

The reduction of end-expiratory carbon dioxide concentration was an early and sole diagnostic sign of air embolism in some cases, and the diagnosis was confirmed by aspiration of air. Other workers (Bethune and Brechner, 1968; Brechner and Bethune, 1971) emphasize the effectiveness of the carbon dioxide analyser in the diagnosis of air embolism. In this study, it is also concluded that the carbon dioxide analyser is a simple, sensitive, and reliable monitor for the diagnosis of air embolism.

In this series, the most effective treatment was aspiration of air through a central venous pressure catheter and the quantity of aspirated air was on one occasion as much as 1003 ml.

**CASE REPORTS**

The following 3 cases, showing interesting clinical features are described in detail.

**CASE 1** (fig. 1).

A 42-year-old woman was to undergo operation for extirpation of a right acoustic neurinoma. At 11.45, arterial pressure was 90/60 mm Hg, pulse rate was 72 beats/min, end-expiratory carbon dioxide concentration was 3.5%, central venous pressure was 34 mm H2O, and respiration was assisted at a rate of about 20 b.p.m. Control arterial blood sampling was done (pH 7.445; PaO2 180 mm Hg; PaCO2 37.5 mm Hg; BE +1.5 m.equiv/l). The operation started at 11.57. At 12.30, central venous pressure increased to 72 mm H2O and end-expiratory carbon dioxide concentration decreased to 2.0%. However, no change was noted in direct arterial pressure, e.g., pulse rate, respiration, or in heart sounds. Air embolism was suspected and air was aspirated at 12.40 (4 ml). After the aspiration of air, central venous pressure and end-expiratory carbon dioxide concentration returned to the normal level gradually.

In summary, air embolism was diagnosed only by the decrease of end-expiratory carbon dioxide concentration and the increase of central venous pressure and confirmed by aspiration of intravascular air.

**CASE 2** (figs. 2 and 3).

Emergency suboccipital craniectomy and the extirpation of a cerebellar haemangioblastoma were attempted on a 36-year-old woman to relieve the impending herniation. Anaesthesia was induced with thiopentone and suxamethonium and maintained with nitrous oxide, oxygen, and halothane. The operation began at 16.30.

About 50 min after the beginning of the operation, typical "mill-wheel" murmur was heard through the stethoscope. The operators noticed that the venous plexus of the epidural space between the occipital bone and the first cervical vertebra was torn. At the same time, a marked reduction of the end-expiratory carbon dioxide concentration was noted (4.7 to 1.6%), arterial pressure fell (126/90 to 90/70 mm Hg), and bigeminy was recognized but the heart rate did not change. Immediately after aspiration of about 1 ml of air through the central venous pressure catheter, the murmur disappeared. These changes are shown in the simultaneous record (figs. 2 and 3).

In this case, arterial pressure decreased first, and was followed by the decrease of end-expiratory carbon dioxide concentration. A few minutes later, the ectopic beats and...
irregular respiration appeared. After 422 sec., arterial pressure returned to the normal level, and the ECG returned to normal sinus rhythm.

**Case 3 (fig. 4).**

A 53-year-old man underwent operation for wrapping of a left posterior inferior cerebellar aneurysm. At 10.00, respiratory rate was 20 b.p.m., arterial pressure was 98/72 mm Hg, pulse rate was 82 beats/min, central venous pressure was 52 mm H2O, and end-expiratory carbon dioxide concentration was 2.4%. Arterial sampling was done (pH 7.650; Paco2 230 mm Hg; Paco2 20.7 mm Hg; BE +3.0 m.equiv/l). The operation started at 10.10. Vital signs remained stable for the first 20 min of the surgery. At 10.30, heart rate increased to 102 beats/min and end-expiratory carbon dioxide concentration decreased to 0.6%. Ventricular ectopic beats were recognized at 10.35. Central venous pressure increased to 148 mm H2O. No murmur could be heard because of improper placement of the stethoscope. Air embolism was diagnosed. Arterial blood sampling was taken immediately (pH 7.394; Paco2 39.3 mm Hg; Paco2 44.5 mm Hg; BE +1.5 m.equiv/l). Air was aspirated through the central venous pressure catheter. The sigmoid sinus was found to be torn.

The volume of aspirated air was 82 ml. After aspiration of air, the pulse rate decreased to 74 beats/min, central venous pressure decreased to 75 mm H2O, and end-expiratory carbon dioxide concentration increased to 2.4%. At 11.00, again the end-expiratory carbon dioxide concentration decreased to 1.5%, and 10 ml of air was aspirated. At 11.10, ventricular ectopic beats were recognized. Air was aspirated again at 11.41 (1 ml) and at 12.17 (20 ml). Nitrous oxide discontinued at 12.42. At 13.05, central venous pressure increased to 126 mm H2O and the “mill-wheel” murmur was heard by the esophageal stethoscope placed properly. End-expiratory carbon dioxide concentration remained at a low level. Ventricular ectopic beats were noticed at 13.33. Aspirated air amounted to 1063 ml during 85 min (13.05 to 14.30). The postoperative chest radiogram revealed bilateral homogenous opacity mainly in the lower lung fields.

In summary, multiple episodes of air embolism occurred in this case. A total of about 1230 ml of air was aspirated. Ventricular ectopic beats seemed to appear in association with a considerable decrease of end-expiratory carbon dioxide concentration, which probably indicated the impaired pulmonary circulation. Blood gas analysis showed increase of Paco2 and decrease of Paco2.

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**References**

La fréquence globale de l'embolie gazeuse a été de 22,2 % chez tous les patients opérés en position assise. L'étude prospective de l'embolie gazeuse au cours d'interventions neurochirurgicales effectuées en position assise a montré que l'embolie gazeuse était un signe diagnostic précoce. Les épisodes d'embolie gazeuse se sont également produits en fin d'intervention. Une description des symptômes utilisés en vue du diagnostic est donnée. L'abaissement des concentrations de gaz carbone notées en fin d'expiration, a constitué un signe diagnostic précocé en faveur d'une embolie gazeuse. Dans 18 cas, le traitement a consisté essentiellement en une aspiration de l'air par l'intermédiaire du cathéter destiné à mesurer la pression veineuse centrale et une suppression de l'administration de protoxyde d'azote. Trois observations sont rapportées en détail.

**PROSPEKTIVE UNTERSUCHUNG DER LUFTEMBOLIE**


**ESTUDIO PROSPECTIVO DEL EMBOLISMO AÉREO**

El embolismo aéreo es una complicación potencialmente fatal. Fue llevado a cabo un estudio prospectivo del embolismo aéreo durante neurocirugía en la posición sentada. La frecuencia global del embolismo aéreo fue del 22,2 por ciento en todos los pacientes operados en la posición sentada y del 40 por ciento en los casos de craniectomia occipital. Casi todos los episodios ocurrieron en el estadio inicial de la operación, sin embargo, también ocurrió embolismo aéreo en el estadio final de la operación. Son descritos los signos utilizados para el diagnóstico. Un signo diagnóstico precoz de embolismo aéreo fue la disminución de la concentración espiratoria final del anhidrido carbónico. El tratamiento principal en 18 episodios consistió en una aspiración de aire por el catéter de la presión venosa central e interrupción del óxido nitroso. Tres casos son descritos detalladamente.