Venous air embolism in a child undergoing posterior fossa craniotomy: a case report

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The incidence of venous air embolism in children undergoing neurosurgical procedures in the sitting position may be as high as 33 per cent. It may be more serious in children because smaller total volumes of air can produce serious physiologic disturbances or fatalities, and the risk of systemic air embolism through a patent foramen ovale or patent ductus arteriosus may be greater than in adults. The case of a six-year-old child who sustained four separate episodes of air embolism while undergoing posterior fossa exploration is presented. Early episodes were well tolerated, but later episodes produced clinical instability. A total of 11 cc of air was recovered from an indwelling right atrial catheter, and the patient recovered uneventfully. This case report illustrates the physiologic changes produced by venous air embolism and reviews the importance of adequate monitoring techniques and early treatment.

Key words

COMPLICATIONS: air embolism; EMBOLISM: AIR;
ANAESTHESIA: paediatric.

Air embolism is a potential complication of neurosurgical cases done in the sitting position. In the adult population, the incidence ranges from 11 to 60 per cent during procedures such as suboccipital craniotomy or cervical exploration.^{1,2}

The incidence of venous air embolism during similar sitting-position cases in children is not well known, but has been reported to be as high as 33 per

cent.³ The use of monitoring devices such as the Doppler ultrasonic bubble detector, end-tidal capnography, pulmonary artery catheterization, and right atrial catheterization have led to early identification of air and made immediate treatment possible. Early detection, identification of the site of entry, and attempts at air aspiration often attenuate or prevent the serious consequences of air in the pulmonary arterial tree.⁴ Physiologic abnormalities that can be the consequence of venous air embolism include mechanical pulmonary vascular obstruction, pulmonary vasoconstriction, hypoxaemia, increased airway resistance, decreased lung compliance, and myocardial ischaemia.⁵ In the paediatric patient, a smaller total volume of air may produce these physiologic changes, and the risk of systemic air embolism is also present if air crosses through a patent foramen ovale or patent ductus arteriosus. Prevention and/or rapid treatment of air embolism is extremely important in children. Sensitive monitoring and vigilant observation are necessary to prevent air from entering or passing undetected until a critical air volume causes disastrous physiologic derangements. The following case serves to illustrate these points.

Case report

A six-year-old female weighing 20 kg was admitted with increasing lethargy, vomiting, and ataxia. A computerized axial tomographic scan revealed a large right cerebellar mass, felt to be compatible with cerebellar astrocytoma and secondary hydrocephalus. A Scott ventricular cannula was placed in the right lateral ventricle under local anaesthesia, and drainage of CSF resulted in almost complete resolution of symptoms. Three days later, she was scheduled for posterior fossa exploration and excision of the tumour in the sitting position.

The patient received no premedication. On ar-

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rival in the operating room she was alert and co-operative. After preoxygenation, anaesthesia was induced with intravenous thiopental $4 \text{ mg} \cdot \text{kg}^{-1}$. She was intubated with a 5.5 mm wire-reinforced tracheal tube without difficulty following neuromuscular block with pancuronium $0.1 \text{ mg} \cdot \text{kg}^{-1}$, and controlled ventilation with nitrous oxide 50 per cent in oxygen was begun. An additional 18-gauge peripheral IV, a 20-gauge radial artery catheter, and a central venous catheter introduced from the right antecubital fossa were positioned.

Placement of the central venous catheter in the lower portion of the right atrium was verified by chest x-ray. The catheter was pulled back approximately 2 cm so that the tip would lie in the upper to mid-atrium. Additional monitoring included ECG, esophageal stethoscope, rectal temperature, a nerve stimulator, and a precordial Doppler verified to be in correct position by the Tinker test.⁶

The patient was placed in the full upright (90 degree) position. The gradient between the incision site and right atrium was approximately 18 cm. Blood pressure and pulse remained stable at 125/80 mmHg and 120 bpm respectively. Anaesthesia was maintained with N_2O 50 per cent in oxygen, intravenous thiopental, fentanyl, and pancuronium. PaO_2 ranged from 251 to 265 mmHg, and PaCO_2 was maintained between 27 and 31 mmHg. The operation proceeded uneventfully until just after opening of the dura, when a change in Doppler tones suggested air embolism and 1 cc of air was aspirated through the right atrial catheter. Continuing sounds on the Doppler indicated further air bubbles, but no air could be aspirated. Treatment with 100 per cent oxygen, positive-pressure ventilation, and saline irrigation resolved the signs of air entrainment. Surgery continued after a careful search revealed no obvious site of air entry. Over the next 30 minutes, frequent signs of air entry were heard from the Doppler, and a total of 3 cc of air aspirated from the right atrium. At no time did the patient exhibit bradycardia or other arrhythmias, but the blood pressure fell at one point to 75/40 mmHg. PaO_2 was 231 mmHg and PaCO_2 was 36 mmHg. Treatment was continued with 100 per cent oxygen, 10 cm H_2O PEEP was added to the breathing circuit, and the incision was packed with wet sponges. This resolved the clinical and Doppler signs of embolism. Estimated blood loss to this point had been replaced with 150 cc of packed red cells, and

arterial blood gases (100 per cent oxygen) were: PaO_2 475 mmHg, PaCO_2 31 mmHg, pH 7.48. Blood pressure had stabilized at 90/60 mmHg, and removal of the saline packs from the wound did not produce signs of recurrent air entry. Surgery continued, nitrous oxide was reintroduced, and the tumour was excised without further incident. During the closure of the galea and scalp incision, Doppler sounds again indicated air entry and the blood pressure decreased to 60/30 mmHg. Although Doppler sounds were almost continuous for several minutes, air could only intermittently be aspirated from the catheter and a total of 7 cc of air was removed. Again, treatment with 100 per cent oxygen, positive-pressure ventilation, air aspiration, intermittent jugular compression, saline irrigation and packing of the wound, and 2.5 mg of intravenous ephedrine eliminated the signs of air entry, and the blood pressure rose to 115/70 mmHg. A large scalp vein was implicated as the point of air entry, this was ligated, and closure was completed without incident. On arrival in the recovery area, the patient was responsive with spontaneous ventilation and no demonstrable neurologic deficit. She was extubated without difficulty 30 minutes after arrival and went on to recover uneventfully.

Discussion

Air entrainment is dependent upon the magnitude of the negative pressure developed between the site of entry and the right heart. Although this risk seems obvious to patients in the sitting position, air entry is also possible in other surgical positions if the potential for a negative-pressure gradient exists.^{4,7} During craniotomy, sites of air entry can include diploic veins, dural sinuses, large veins in the cervical muscles, or veins in the scalp. Although entry through open channels in the operative field is most likely, air has been reported entering around the pin sites of a pin head-holder.⁸ In rare cases, no site has been able to be identified.⁹ Albin and co-workers¹⁰ have reported that most episodes of air embolism are likely to occur at the beginning of surgery (78.7 per cent). This compares to an incidence of 18 per cent at the end of the surgical procedures, and 3.3 per cent during operation. Clearly, the risk of air embolism is greater in patients in the sitting position. There appears to be little argument that these patients should be monitored carefully for such an event.

The incidence of venous air embolism in children undergoing neurosurgical procedures is not well established. Millar¹ reported experience with 110 cases in the sitting position, 18 of whom were age 10 or under. None had clinical evidence of air embolism. Similarly, Allan¹¹ found no evidence of venous air embolism in 18 infants undergoing posterior fossa exploration. Cucchiara and Bowers³ reported a 33 per cent occurrence of air (by Doppler detection) in 48 paediatric cases of suboccipital craniotomy. Children are also at risk for sustaining air embolism during other procedures and it has been reported during arthrography, arteriography, cisternal air myelography, and pneumoencephalography. Of nine reported cases of venous air embolism in children during these diagnostic radiologic procedures, seven patients died.^{12,13}

The earliest reports of death from venous air embolism described air filling the right side of the heart, obstructing further circulation of blood through the heart.^{14,15} This "air-lock" is usually the result of a large bolus of air entering the veins. Gradual introduction of air, or entrainment of a smaller amount, may be tolerated somewhat better. Adornato *et al.*¹⁶ found that slow venous infusion of $0.01\text{--}2.0\text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ of air in dogs produced gradually progressive haemodynamic changes (increased pulmonary vascular resistance, decreased systemic vascular resistance, decreased cardiac output, and hypotension) as the rate of infusion increased. Bolus injection of as little as $1.0\text{ ml}\cdot\text{kg}^{-1}$ of air produced shock and ECG evidence of myocardial ischaemia. Larger boluses (up to $13.3\text{ ml}\cdot\text{kg}^{-1}$) were usually immediately fatal. Hybels¹⁷ has suggested that infusion rates of $5\text{--}8\text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ in the dog can be fatal, as can a bolus of $3\text{ ml}\cdot\text{kg}^{-1}$. Accidental bolus injection of 100 cc has been reported fatal in an adult human.¹⁸ Albin *et al.* have noted marked perfusion deficits on technetium lung scans in adult patients in whom more than a total of 50 cc of air was aspirated through a right atrial catheter.⁴ The physiologic changes associated with slower infusion are distinct from the sudden air bolus that distends the heart. Smaller amounts of air enter the pulmonary circulation, causing a rise in pulmonary arterial pressure, a rise in central venous pressure, and a progressive decrease in cardiac output and rise in systemic vascular resistance. It is reasonable to extrapolate that these changes could

result from entry of very small amounts of air in the paediatric patient.

Recently, Bedford¹⁹ re-emphasized the potential for systemic air embolism via a patent foramen orale (PFO) by measuring positive interatrial pressure differences in 7 of 11 patients operated in the sitting position during application of PEEP. Two patients had such a gradient present prior to positive pressure application. The foramen ovale is at least probe-patent in approximately 35 per cent of the general population.²⁰ Since air embolism may occur in up to 30 per cent of patients in the sitting position, systemic embolism could occur in ten per cent of all patients operated in the sitting position.²¹ In the infant, pulmonary vascular resistance is initially high, and is also rapidly responsive to stimuli such as hypoxia and acidosis.²² If the ductus arteriosus is still able to open in response to hypoxia, an increase in right-sided pressures secondary to pulmonary air embolism can direct further blood (and air) through either the ductus or a PFO into the systemic circulation.²³ Young infants may therefore be more at risk for systemic embolization following venous air entrainment.

The Doppler ultrasonic bubble detector is a sensitive and reliable means of detecting air entry into the right side of the heart.^{2,24,25} It appears to be equally as sensitive in the paediatric population. Since smaller volumes of air may produce significant physiologic changes in children, the opportunity for early detection afforded by the Doppler in this population is essential.

Since Michenfelder *et al.*²⁶ first suggested placement of a right atrial catheter for aspiration of air, much work has been devoted to correct placement of the catheter for optimal air recovery. Bunegin and Albin¹¹ have shown that the optimal position for a conventional single-lumen catheter is at the junction of the superior vena cava and the right atrium. They were able to demonstrate 25–58 per cent air recovery in the upright position through a single-lumen catheter, using a right atrial model.²⁷ Use of an inflated balloon-tipped single-lumen catheter enabled 91 per cent recovery of air when the atrium was at an 80-degree angle from the horizontal.²⁸ Clinically this approximates the sitting position used during posterior fossa surgery. Further investigation has indicated that perhaps greater than 95 per cent of the air entering the right

heart might be removed with the use of a balloon-tipped multi-orifice catheter.²⁷

Catheter placement in infants and children is admittedly sometimes difficult. Some may feel that persistent attempts at placement of a right atrial catheter increase the risk of complications and outweigh the advantages of air aspiration. However, since air embolism can occur suddenly with serious consequences in children, the opportunity for therapeutic intervention provided by a right atrial catheter should not be neglected.

When a right atrial catheter is in place, aspiration of venous air is possible, reducing the volume of air entering the pulmonary vasculature. In adults with detectable air embolism air can be aspirated in up to 75 per cent of cases.¹⁰ In contrast, Cucchiara³ reported that air could be aspirated in only 38 per cent of his paediatric patients with detectable Doppler evidence of air. Although the overall incidence of air embolism does not appear to be significantly different between children and adults, it appears to be more haemodynamically significant in children. Cucchiara³ further noted that 69 per cent of children undergoing suboccipital craniotomy with evidence of air embolism became hypotensive, as compared to 36 per cent of patients over 12 years of age.

In our case, there were apparently several sites of air entry, not an uncommon situation during posterior fossa surgery. Humphreys²⁹ has suggested that posterior fossa and posterior cervical exploration in children be done in the prone position because the highly vascularized occipital bone and poorly defined dural sinuses in the infant and young child enhance the risk of air embolism. A total of 11 cc of air was aspirated from our patient, and it is apparent that a greater amount passed the catheter tip and entered the pulmonary vasculature. The earlier episodes were well tolerated by the patient, but later episodes produced hypotension. Although each episode was transient, small amounts of air were recovered, and rapid treatment instituted, the total volume and repeated insult were sufficient to cause haemodynamic instability. Perhaps a more optimal placement of the right atrial catheter (SVC and RA junction) would have allowed for a greater yield of aspirated air and prevented the subsequent clinical instability.

Because of the significant gradient that exists in

posterior-fossa exploration in the sitting position, and because the entrainment of even a small amount of air can lead to hypotension and arrhythmias in children, reliable monitoring for venous air embolism and adequate treatment, should it occur, are important. The use of a Doppler ultrasonic detector and the routine placement of a right atrial catheter will help prevent undetected air entry. Only prompt identification of the entry site and vigorous supportive measures will help prevent the more serious consequences of air embolism in the child.

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Résumé

On rapporte une incidence d'embolie aérienne aussi haute que 33 pour cent en neurochirurgie pédiatrique en position assise. De tels événements peuvent être plus sérieux chez les enfants parce que des plus petits volumes d'air produisent des désordres physiologiques graves ou même des décès; de plus, le risque d'embolie aérienne artérielle à travers un foramen ovale perméable ou un canal artériel peut être plus élevé que chez l'adulte. Ce travail rapporte quatre épisodes d'embolie aérienne chez un enfant de six ans au cours d'une exploration de la fosse postérieure en position assise.

Les premiers incidents ont été bien tolérés mais les derniers ont conduit à une période d'instabilité. Un volume total d'air de 11 cc a été récupéré par aspiration dans un cathéter placé dans l'oreillette et le malade s'en est tiré sans séquelle. Ce compte-rendu illustre les changements physiologiques provoqués par l'embolisation aérienne veineuse et souligne, de nouveau, toute l'importance d'un monitoring adéquat qui permet de conduire à un traitement immédiat.