The sitting position for neurosurgery in children: a review of 16 years’ experience†

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Background. Use of the sitting position for neurosurgery is controversial. The main concern is the risk of venous air embolus (VAE) and its sequelae.

Methods. The paediatric neurosurgeons at our institution routinely use the sitting position for posterior fossa and pineal surgery, and a retrospective audit of the incidence of VAE from 1982 to 1998 has been performed.

Results. Venous air embolism, defined as a fall in end-tidal carbon dioxide pressure >0.4 kPa, was detected in 38 of 407 operations (9.3%). A fall in systolic arterial pressure >10% accompanied the VAE in nine out of 43 episodes (20.9%); this represents 2% of all operations. All VAE episodes responded promptly to treatment and there was no perioperative morbidity or mortality directly attributed to it.

Conclusions. This is the largest study of the incidence of VAE in children undergoing neurosurgery. Our results suggest that the sitting position can be used safely for neurosurgery in children.

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Controversy surrounds the use of the sitting position for neurosurgery.1 The main concern is the risk of venous air embolus (VAE) and its sequelae. The reported incidence of VAE in adults undergoing neurosurgery in the sitting position varies from 7 to 50%.2–8 Only three studies have looked specifically at the incidence of VAE in children undergoing neurosurgery in the sitting position with a rate of between 26 and 69%. These studies were all relatively small with between 12 and 48 patients studied.8–10

The paediatric neurosurgeons at our institution routinely use the sitting position for posterior fossa and pineal surgery, and for selected foramen magnum decompressions (FMD). Following the availability of a capnogram suitable for all paediatric patients, an on-going retrospective audit of the incidence of VAE in the sitting position has been performed. The results provide a much larger body of data than is currently available in the literature on the risk of a clinically significant VAE during neurosurgery in the sitting position in children.

Methods
The case notes of children who underwent neurosurgery in the sitting position between February 1982 and February 1998 were examined retrospectively every 4 yrs. The patients were identified from the neurosurgical database and the operating department records. The case notes were retrieved and the intraoperative position noted; all children who underwent surgery in the sitting position were included in the analysis.

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Physical characteristics, including patient age, weight, and histological diagnosis, were collected. The anaesthesia records were examined for evidence of VAE, defined as a fall in end-tidal P\textsubscript{CO}_2 greater than 0.4 kPa. Changes in systolic arterial pressure, or heart rate, greater than 10% from baseline, and any association with a fall in end-tidal P\textsubscript{CO}_2, were recorded. The postoperative notes were studied with reference to the requirement for postoperative positive pressure ventilation and were used together with the follow-up notes to document any unexpected neurological sequelae. The data were entered into a Microsoft Access database for analysis.

More than 90% of the cases were anaesthetized by one of three consultant paediatric neuroanaesthetists (A.M., A.McE., and E.F.). The anaesthetic technique changed with the standard practice for the time. After anaesthetic review, the majority of the children received either oral or i.m. atropine premedication. Induction of general anaesthesia was either inhalation or i.v., dependent on patient preference. Following orotracheal intubation, a balanced maintenance technique with fentanyl, either tubocurarine or vecuronium, and less than 1 MAC concentration of halothane, isoflurane, or sevoflurane delivered in either nitrous oxide/oxygen or air/oxygen mixture was used; air was only available in the last few months of this study. No positive end-expiratory pressure (PEEP) was applied to the lungs and minute ventilation was adjusted to achieve mild hypocapnia.

After induction of anaesthesia, the child was gradually moved to the sitting position over a 5 min period, with arterial pressure monitoring, and given up to 10 ml kg\textsuperscript{-1} of i.v. crystalloid if required. The surgery took place with the child in an operating chair. Children less than 40 kg were positioned with their feet level with their buttocks, while those greater than 40 kg had dependant legs. Monitoring consisted of electrocardiography, capnography, pulse oximetry (from 1986), and direct systemic arterial pressure measurement. The lower alarm limit for the end-tidal P\textsubscript{CO}_2 value was set 0.5 kPa below the baseline end-tidal value. Venous access was secured with two peripheral i.v. cannulae. Neither central venous lines nor anti-gravity suits were used routinely. Preoperative contrast echocardiography, to screen for a patent foramen ovale, was not routinely performed on children undergoing surgery in the sitting position. Chi-squared analysis was used to determine any difference in the incidence of VAE between patients with different histological diagnosis.

Results

The case notes of 407 children who underwent neurosurgical operations in the sitting position at Great Ormond Street Hospital for Children between February 1982 and February 1998 were studied. Three hundred and seventy-six operations were performed for excision of a posterior fossa mass, 15 for pineal surgery, and 16 for FMD. More than 99% of these operations were performed by one of three paediatric neurosurgeons. The age of the patient ranged from 6 weeks to 17 yrs, with a median age of 5 yr. The median weight was 19 kg, with a range of 3–70 kg. The male to female ratio was 1.5:1. No child had clinical evidence of a septal defect.

Venous air embolism, defined as a fall in end-tidal P\textsubscript{CO}_2 greater than 0.4 kPa was detected in 38 of 407 patients (9.3%), and occurred more than once during the same procedure in three patients. There were 43 separate episodes of VAE. None of the 11 children who were less than 1 yr old had an episode of VAE. The incidence of VAE was assessed by patient weight and histological diagnosis (Figs 1 and 2). Statistical analysis using the chi-squared test revealed a significantly higher incidence of VAE in patients with pineal tumours compared with those with astrocytoma (P=0.001). There was no significant difference between the incidence of VAE in children undergoing pineal surgery and those with other histological diagnoses. VAE was accompanied by hypotension (>10% fall in systolic arterial pressure) in nine out of 43 episodes (20.9%) (Fig. 3). The three most severe cases of hypotension were as follows.

Case 1: a fall in end-tidal P\textsubscript{CO}_2 to 1.2 kPa, associated with a 47% reduction in systolic arterial pressure, occurred during sub-occipital craniotomy for resection of a medulloblastoma in a 3-yr-old boy. The response to treatment was prompt. Postoperative examination revealed a mild hemiparesis, which resolved. The hemiparesis was thought not to have been a result of this episode.

Case 2: a fall in systolic arterial pressure of 47%, associated with tachycardia and a fall in end-tidal P\textsubscript{CO}_2, occurred in a 9-yr-old boy during resection of a meningioma. The estimated intraoperative blood loss was 1900 ml. Postoperative examination revealed mild ataxia and hemiparesis, which subsequently resolved.

Case 3: during a repeat FMD in a 17-yr-old boy, a sudden fall in systolic arterial pressure from 100 to 30 mm Hg, associated with a fall in end-tidal P\textsubscript{CO}_2 to 2.5 kPa, was recorded. There was an immediate response to i.v. fluids and vasopressors, and a venous bleeding site thought to have been the site for air was found and managed. He made a full postoperative recovery.

The timing of the VAE relative to surgical events was recorded on 27 occasions. Of these, 12 occurred on opening of the dura, four during tumour dissection, and 11 on closure of the dura. There was no unexplained perioperative morbidity or mortality in the patients with VAE that would suggest a paradoxical air embolus. Management of a suspected VAE included immediate bilateral jugular venous compression, covering the surgical field with saline-soaked swabs, and ventilation with 100% oxygen. I.v. fluids were given to increase the venous pressure and maintain arterial pressure.

All children were haemodynamically stable following induction of general anaesthesia and positioning. Intraoperative cardiovascular instability (defined as >10%
change in systolic arterial pressure, or heart rate, from baseline) occurred in 98 of 407 patients (24.1%). Most were transient bradycardias or tachycardias, with or without hypotension, associated with tumour manipulation. One or more episodes of transient hypotension occurred in 26 patients; they were the result of VAE in eight patients and because of severe blood loss in a further three patients. There was no change in the continuously monitored capnograph of the 15 patients in whom the cause for the hypotension was not established.

Sixty-nine of the 407 patients (16.9%) were electively ventilated postoperatively; VAE had occurred in 13 of the 69 cases. Before 1989, patients who were cardiovascularly unstable intraoperatively were electively ventilated, but VAE was not an indication for postoperative ventilation during any part of the study period. Figure 4 shows the change in postoperative ventilation practice with time. Postoperative ventilation was required for more than 72 h in only two patients, neither of whom had evidence of VAE; one because of a bizarre respiratory pattern and the other because of a bulbar palsy. There was no morbidity known to be associated with posterior fossa surgery, such as tension

Fig 1 Incidence of VAE during neurosurgery in the sitting position in relation to patient weight.

Fig 2 Incidence of VAE during neurosurgery in the sitting position in relation to surgical pathology (FMD = foramen magnum decompressions).

Fig 3 Systolic hypotension associated with VAE.

Fig 4 Changes in use of postoperative ventilation with time.
pneumocephalus, macroglossia, quadriplegia, or peripheral nerve damage.

Discussion

The use of the sitting position for neurosurgery is controversial and has been reported to be in decline. The main concern is the risk of VAE and its sequelae. Although there are several published reports of the incidence of VAE in the sitting position in adults, there are no large series that look at the incidence of VAE in children. The reported incidence, as detected by Doppler ultrasonography, in adults ranges from 7 to 50%. We found a lower incidence of VAE in the sitting position in children (9.3%) than previously reported, together with a low incidence of VAE associated hypotension (20.9% of 43 VAE episodes). There are several possible reasons for our findings.

It may be that the incidence of VAE in the sitting position is lower in children than in adults. Although Matjasko and colleagues reported a significantly higher incidence of VAE in children (62%) compared with adults (23%) in a review of 554 neurosurgical procedures in the sitting position, only 13 patients were 12 yrs or less. However, a retrospective comparison between adults and children undergoing suboccipital craniotomy in the sitting position at the Mayo Clinic showed a lower incidence of VAE in children (16 of 48) than in adult controls (22 of 48). There are two prospective paediatric studies in the literature on the incidence of VAE in the sitting position. Meyer and colleagues reported a 26% incidence of VAE in the sitting position, using capnography, in 30 children who were not treated with lower body positive pressure or PEEP. Fuchs and colleagues studied 24 children undergoing neurosurgery in the sitting position and reported a VAE incidence of 37% as detected by Doppler.

A possible explanation for the low incidence of VAE we report is the finding of relatively high dural sinus pressures in children compared with adults. As a negative venous pressure relative to atmospheric pressure is necessary for venous air entrainment to occur, factors that might affect the intracranial venous pressure in the sitting position have been studied. Iwabuchi and colleagues examined the dural sinus pressure (confluens sinuum pressure, CSP) under various conditions in 47 cases. In the sitting position, all adults had a negative CSP whereas all eight children less than 9 yrs old showed a positive pressure. This difference in CSP in the sitting position between adults and children would suggest a lower risk of VAE in children in this position and may help to explain the low incidence of VAE in our population. However, the findings of Iwabuchi are not supported by those of Grady and colleagues who investigated the relationship of superior sagittal sinus pressure (SSP) to head position in 15 children. In five of the 15 children, the SSP was sub-atmospheric at 90° torso elevation. The effects of PEEP and bilateral internal jugular venous compression, two commonly used treatments for VAE, were also studied. Bilateral jugular venous compression, but not a PEEP of 10 cm H2O, caused a significant increase in SSP at every degree of head elevation studied. This latter finding supports the value of one of our immediate treatment strategies for a suspected VAE.

It is not possible to directly compare the incidence of VAE between studies where different methods of detection are used. Transoesophageal echocardiography (TOE) is an extremely sensitive method for detecting intracardiac air and it is not surprising that the reported incidence of VAE is as high as 76% in adult studies when TOE is used to detect it. However, TOE will detect tiny microbubbles that may be of no clinical importance. The majority of British practice relies on capnography to detect entrained air that enters the pulmonary circulation. A fall in end-tidal Pco2 occurs with VAE because air within the pulmonary circulation leads to an increase in physiological deadspace. Capnography is the technique of choice for the detection of VAE at our hospital and has been used for all patients undergoing surgery in the sitting position since February 1982.

We recorded every fall in end-tidal Pco2, 0.5 kPa as VAE whether or not there was any associated cardiovascular instability. The findings of Mammotho and colleagues support capnography as a satisfactory method for the detection of VAE in the clinical situation. In this study, 21 patients undergoing neurosurgery in the sitting position were continuously monitored with TOE and capnography. Microbubbles appeared in the right atrium in all patients and the severity was graded according to a microbubble scoring system as follows: grade 0 (no microbubbles), grade 1 (less than five microbubbles per frame), grade 2 (10–12 microbubbles per frame), and grade 3 (too many microbubbles to be counted per frame). A fall in end-tidal Pco2 greater than 0.5 kPa occurred with every episode of grade 2 and grade 3 air embolus.

Cardiovascular instability in addition to a fall in end-tidal Pco2 implies a larger air embolus than that detected by capnography alone. There is a theoretical argument that the incidence of VAE associated hypotension in children might be higher than in adults. This is because an equivalent air bubble would be larger relative to blood volume in children and, therefore, more likely to cause cardiovascular compromise. This theory is supported by the findings of a comparison between adults and children by Cucchiara and Bowers at the Mayo Clinic. In their retrospective review of 96 patients undergoing sub-occipital craniotomy in the sitting position the incidence of VAE associated hypotension, defined as a fall in systolic arterial pressure of 25 mm Hg, was greater in children (69%) than in adults (36%). However, the two prospective paediatric studies in the literature report conflicting results. Severe hypotension, defined as a fall in mean arterial pressure of at least 25 mm Hg, occurred in all children with VAE, as detected by capnography, in the study by Meyer and colleagues. However, no child developed VAE associated hypotension.
in the study of 24 children undergoing neurosurgery in the sitting position by Fuchs and colleagues. In our much larger paediatric series we report a low incidence of VAE associated hypotension (nine of 43 VAE episodes or 20.9%). It is not possible to directly compare our results with the incidence of VAE associated hypotension reported in other studies because the definitions used either for the diagnosis of VAE, or hypotension, or both, are different. However, the criteria for hypotension in our study are very strict; had we used Doppler for detection of VAE it is likely that we would have reported a higher number of VAE and consequently an even smaller percentage of VAE episodes with associated hypotension.

There was no clinical evidence of septal defects in our patients but this does not exclude a probe patent foramen ovale which are common in the general population. We do not think, based on our data, that this provides a sufficient risk to warrant routine preoperative echocardiography, while we are aware that any large air embolus may be associated with paradoxical embolism. The routine use of central venous catheters is sometimes recommended. They were not used routinely in our series except to provide good venous access. The most reliable route to the right atrium in small children is via the right internal jugular vein. The flexed head position with the short neck of the child may cause venous obstruction thereby negating the benefits of the sitting position.

In our series apart from two cases of mild hemiparesis, there was no postoperative morbidity in the 38 children in whom a VAE was diagnosed. This lack of associated morbidity following VAE in the sitting position has been confirmed by other large studies. Reports of complications directly related to the occurrence of VAE are for the most part individual case reports. Experience from the Mayo Clinic of 3827 neurosurgical procedures in the sitting position, between 1966 and 1983, revealed only two patients with morbidity related to air embolus; one patient died postoperatively from acute respiratory distress syndrome and the other had a paradoxical air embolus with severe neurological sequelae. The only intraoperative death directly caused by VAE was a patient having surgery in the prone position.

The reasons the sitting position is chosen for posterior fossa surgery in preference to one of the horizontal positions include improved surgical access and orientation, and reduced bleeding. In a retrospective review of 579 posterior fossa craniectomies, Black and colleagues found that the incidence of transfusion of greater than two units of blood was significantly higher in the horizontal than in the sitting patients. Also, postoperative cranial nerve function was significantly better in patients operated on in the sitting position compared to a horizontal position.

The use of a horizontal position does not eliminate the risk of VAE. In a retrospective review of 704 patients undergoing neurosurgery in the lounging position, VAE was detected by Doppler ultrasonography in nine of 34 children (26.5%). Black and colleagues report a 12% incidence of VAE in the horizontal position in 74 adult patients monitored with praecordial doppler. VAE was diagnosed by TOE in eight of 12 infants undergoing cranietomy for repair of craniosynostosis in the supine position in a prospective study by Harris and colleagues.

Although we acknowledge the limitations inherent in a retrospective review, this series provides a much larger body of data on the incidence of VAE in children than is currently available in the literature. Anecdotal evidence and the results of several retrospective adult studies have caused many to abandon the sitting position. We report a low incidence of VAE (9.3%), and VAE associated hypotension occurred in only 2% of 407 operations. Apart from mild hemiparesis, which subsequently resolved, there was no perioperative morbidity or mortality related to VAE over the 16-yr study period. We do not suggest that there should be any complacency about the use of the sitting position but believe that, with meticulous surgical and anaesthetic technique, the position is safe.

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