

Venous Air Embolism during Endoscopic Strip Craniectomy for Repair of Craniosynostosis in Infants

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Background: Various studies have reported an incidence of venous air embolism (VAE) as high as 82.6% during surgical procedures for craniosynostosis. There has been an increase in the use of minimally invasive, endoscopic surgical procedures, including applications for endoscopic strip craniectomy. The current study prospectively evaluated the incidence of VAE during endoscopic strip craniectomy.

Methods: Continuous, intraoperative monitoring for VAE was performed using precordial Doppler monitoring. A recording was made of the Doppler tones and later reviewed to verify its accuracy.

Results: The cohort for the study included 50 consecutive neonates and infants ranging in age from 3.5 to 36 weeks and ranging in weight from 3 to 9 kg. Surgical time varied from 31 to 95 min for a total of 2,701 min of operating time, during which precordial Doppler tones were auscultated. In 46 patients, there was no evidence of VAE. In four patients, there was a single episode of VAE. Two of the episodes of VAE were grade I (change in Doppler tones), and two were grade II (change in Doppler tones and decrease in end-tidal carbon dioxide). No grade III (decrease in systolic blood pressure by 20% from baseline) VAE was noted.

Conclusion: In addition to previously reported benefits of decreased blood loss, decreased surgical time, and improved postoperative recovery time, the authors noted a low incidence of VAE during endoscopic strip craniectomy in neonates and infants.

THE applications of minimally invasive surgical procedures continue to increase in the pediatric population and in the adult population. These techniques have also been applied to neurosurgical procedures, including repair of craniosynostosis. The initial experience with the use of endoscopic strip craniectomy for repair of craniosynostosis has been promising, with benefits such as decreased blood loss, decreased need for homologous blood, decreased surgical time, and a more rapid postoperative recovery.^{1,2}

In addition to the obvious risks of blood loss associated with open craniectomy, Faberowski *et al.*³ have recently reported their prospective study on the incidence of

venous air embolism (VAE) during these procedures. They identified a total of 64 episodes of VAE in 19 of 23 patients (82.6%), with 6 patients having associated hypotension. Because there is limited bleeding with endoscopic strip craniectomy, we hypothesized that the risk of VAE may also be decreased. This study prospectively evaluated the incidence of VAE during endoscopic strip craniectomy in 50 neonates and infants.

Materials and Methods

Surgical Technique

After preparation of the scalp with povidone-iodine solution, the incision sites of the scalp were infiltrated with 0.25% lidocaine with epinephrine (1:200,000). A 2-cm incision was made over the involved suture (two 2-cm incisions were made for sagittal sutures). Subgaleal dissection was performed using blunt dissection with endoscopic assistance. The endoscopic system does not use water instillation or gas insufflation to provide visualization of distal structures and tissues. A burr hole was drilled next to the involved suture, and endoscopic assistance was used to achieve dural dissection from the suture. Emissary veins were coagulated using a bipolar coagulator. After subgaleal and epidural exposure, a lateral paramedian osteotomy was made using bone-cutting scissors, and the involved suture was removed. The surgical technique for endoscopic strip craniectomy is described in detail elsewhere.^{1,2}

Study Protocol

After institutional review board approval (The University of Missouri, Columbia, Missouri) and verbal parental consent, 50 consecutive patients presenting for endoscopic strip craniectomy were enrolled in this prospective study. Anesthetic care included inhalation induction with sevoflurane in oxygen-air or oxygen-nitrous oxide followed by placement of a single intravenous cannula. Endotracheal intubation was facilitated by a single dose of either rocuronium (0.7-1 mg/kg) or *cis*-atracurium (0.2-0.3 mg/kg). Maintenance anesthesia consisted of isoflurane in oxygen-air or oxygen-nitrous oxide and fentanyl (2-3 μ g/kg). After induction of anesthesia, an acetaminophen suppository (40 mg/kg) was administered to all patients per rectum. The patients were positioned supine or prone, depending on the surgical requirement. The distance from the top of the surgical field to the right atrium (taken as the mid axillary line)

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was measured. Fluid administration was at the discretion of the anesthesia team.

To monitor for VAE, a precordial Doppler probe (Dual Frequency Doppler; Parks Medical Electronics, Aloha, OR) was placed to the right of the midline at the second or third intercostal space. Our clinical practice additionally includes demonstration of the muffling of Doppler heart tones with sustained lung inflation. It is our contention, from observation of lung movement during median sternotomy, that with sustained inflation, the right middle lobe inflates and is therefore in position between the right atrium and the Doppler probe, further confirming correct placement. Before the start of and at the completion of the surgical procedure, correct placement was further verified by rapid injection of 1–2 ml saline and auscultation of characteristic Doppler tones. When correct placement of the Doppler probe was achieved, the probe was padded around the edges with gauze and held in place with a transparent, occlusive dressing. The precordial Doppler tones were monitored continuously during the procedure and recorded. The tape was then reviewed by one of the authors (J. O. J.) to verify that no intraoperative episodes of VAE had been missed.

The severity of VAE was graded according the scale used by Faberowski *et al.*³, which included (1) Doppler tone changes; (2) Doppler tone changes and an abrupt decrease in end-tidal carbon dioxide (ETCO₂) of 5 mmHg or more; and (3) Doppler tone changes, an abrupt decrease in ETCO₂ of 5 mmHg or more, and a decrease in systolic blood pressure (20% or more from baseline). All data are presented as mean \pm SD. Fluids administered, blood loss, and the height of the surgical site above the right atrium from patients who experienced VAE were compared with the entire cohort of patients using an unpaired, two-tailed *t* test with *P* < 0.05 considered significant.

Results

The cohort studied included 50 consecutive neonates and infants (27 girls, 23 boys) undergoing endoscopic strip craniectomy. The patients ranged in age from 3.5 to 36 weeks (13.2 \pm 6.2 weeks) and ranged in weight from 3 to 9 kg (6.1 \pm 1.6 kg). The surgical procedure included a single suture in 48 patients and two sutures (bicoronal) in 2 patients, resulting in a total of 52 sutures in the 50 patients. The excised sutures included coronal (20), sagittal (19), metopic (12), and lambdoidal (1). Patient positioning included supine for metopic and coronal sutures, true prone for lambdoidal, and modified prone (sphinx) for sagittal. The distance from the highest point of the surgical field to the right atrium was 3.5 to 18 cm (7.8 \pm 3.8 cm). Surgical time defined as the time from skin incision to placement of the final skin suture varied from 31 to 95 min (54 \pm 12.3 min) for a total of 2,701 min of

operating time, during which precordial Doppler tones were monitored. Estimated blood loss varied from 10 to 60 ml (26 \pm 12 ml). No patient received intraoperative transfusions, and two patients received homologous erythrocyte transfusions during the postoperative period. The total amount of intraoperative fluids (lactated Ringer's or normal saline) administered was 201 \pm 76 ml.

In 46 patients, there was no evidence of VAE. In four patients, there was a single episode of VAE. None of the episodes of VAE coincided with the administration of medications or fluids. Two of the episodes of VAE were grade I, and two were grade II. No grade III VAE was noted. One episode of VAE occurred during blunt surgical dissection of the tissue planes, whereas three episodes occurred during saline irrigation of the surgical field after completion of the surgical dissection. Three episodes of VAE occurred with coronal sutures, and one occurred with a metopic suture.

In the four patients in whom VAE occurred, intraoperative fluid administration was 240 \pm 100 ml (*P* = NS compared with the study cohort), estimated blood loss was 32 \pm 10 ml (*P* = NS), and the distance from the right atrium to the surgical site was 4.5 \pm 0.6 cm (*P* = NS). The four episodes of VAE resolved spontaneously or with cessation of surgical manipulation and irrigation of the surgical field with saline.

Discussion

In the current study, an incidence of VAE of 8% was noted (4 of 50 patients) using precordial Doppler monitoring during endoscopic strip craniectomy. None of the four episodes of VAE resulted in hemodynamic compromise. Unlike the study of Faberowski *et al.*³, in which multiple episodes of VAE were noted in many of the patients, there was only a single episode of VAE in the four patients in our study in whom VAE occurred. Only one of the episodes of VAE occurred during surgical dissection of the tissue planes, whereas three episodes of VAE occurred during irrigation of the surgical field during either coronal or metopic suture repair. No episode of VAE was noted during the 19 sagittal synostosis repairs. With endoscopic repair of metopic, coronal, and lambdoidal synostosis, a single skin incision is made. Therefore, with irrigation of the surgical field, we suggest that there may be more pressure on the surgical site because there is limited egress of the irrigation fluid when compared with repair of sagittal synostosis, in which there are two incision sites. Air may be forced into the vascular system rather than entrained, as may occur during the surgical procedure. This observation has led us to change our intraoperative technique so that during irrigation, the head is lowered to a height equivalent to or below the right atrium and less pressure used during irrigation.

Variation in the incidence of VAE has been noted during craniectomy for craniosynostosis. Harris *et al.*⁴ evaluated the incidence of VAE during craniosynostosis surgery in 12 patients under 1 yr of age. Using transthoracic echocardiography, VAE was noted in 8 of 12 patients (66%). Only one infant had hemodynamic consequences of the VAE, which included a decrease in systolic blood pressure of 20 mmHg, premature atrial contractions, and a nodal rhythm. These cardiovascular changes responded to intravenous atropine. Using ETco₂ monitoring, Meyer *et al.*⁵ noted VAE in 3 of 130 patients (2.6%) undergoing open repair of craniosynostosis.

Venous air embolism has also been reported during other types of neurosurgical procedures in pediatric-aged patients. Using precordial Doppler monitoring, Cucchiara and Bowers⁶ reported an incidence of VAE of 33% in a retrospective review of 48 patients, 12 yr of age and younger, during suboccipital craniotomy in the sitting position. Eleven of the 16 patients experienced hypotension during the episode of VAE. Meyer *et al.*⁷ used ETco₂ monitoring and reported an incidence of VAE of 26% in 30 children undergoing surgical procedures in the sitting position without the application of military antishock trousers or positive end-expiratory pressure, whereas no episodes of VAE were noted with inflation of military antishock trousers and the application of positive end-expiratory pressure in an additional 30 patients.

Although the potential for VAE is well-recognized during any procedure in children in which the operative site is above the heart and noncollapsible veins are exposed to the environment, there is a marked variability in the literature in regard to its incidence during neurosurgical procedures. The variability may be partly explained by the monitoring used to detect VAE, as well as the surgical procedure, blood loss, fluid administration, and patient positioning. The highest incidence of VAE (82.6%) was reported by Faberowski *et al.*³ using precordial Doppler monitoring during open craniectomy with blood loss approaching 90% of estimated blood volume.

Several options are available to detect VAE, including echocardiography, precordial Doppler monitoring, ETco₂ monitoring, end-tidal nitrogen monitoring, transcutaneous oxygen-carbon dioxide monitoring, and esophageal stethoscope use, as well as central venous and pulmonary artery pressure monitoring. The most sensitive of these monitors have been shown to be echocardiography and precordial Doppler monitoring.⁸ Precordial Doppler technology is noninvasive, inexpensive,

and easy to learn, making it readily applicable in a busy operating room. The hemodynamic consequences of VAE are generally insignificant, provided that patients are monitored to detect VAE and interventions are provided. However, repeated or ongoing VAE can lead to significant hemodynamic compromise, including reported intraoperative cardiac arrest in a 10-month-old infant.⁹

The low incidence of VAE in our patient population most likely relates to the limited blood loss experienced with the endoscopic approach resulting in less dramatic decreases in right atrial pressure as well as a decreased propensity to have noncollapsible veins exposed to the air. Previous reports have shown a mean estimated blood loss during open procedures as high as 90% of the estimated blood volume,⁷ whereas the mean blood loss noted in our patients was 26 ml (5-6% of estimated blood volume), with only two patients requiring homologous blood transfusions. In addition to benefits such as decreased blood loss, decreased surgical time, and improved postoperative recovery time, we noted a low incidence of VAE during endoscopic strip craniectomy. The incidence in the current study of 8% using precordial Doppler monitoring is lower than that reported during open procedures. Despite the low incidence of VAE in our patient population, given the ease and noninvasive nature of Doppler monitoring and the potential for serious consequences of VAE, we continue to recommend monitoring during such procedures.

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