

postoperative increase in BG is not a consistent finding. If a nonglucose-containing solution is used for intraoperative fluid management, intraoperative BG monitoring is suggested, especially if the preoperative fasting period has been prolonged. We found the Glucometer® technique to be an accurate bedside method for BG monitoring even at low BG concentrations.

Because intraoperative administration of 5% glucose-containing solutions invariably results in hyperglycemia, a less concentrated glucose-containing solution might be preferable for routine intravenous fluid maintenance during surgery in healthy children.

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## Venous Air Embolism and Cardiac Arrest during Craniectomy in a Supine Infant

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Venous air embolism (VAE) is a common complication of neurosurgical procedures done in the sitting position.<sup>1</sup>

VAE probably occurs in 7-45% of sitting<sup>2-4</sup> and 10-17% of prone procedures<sup>4,5</sup> and occasionally, in the supine<sup>4,6</sup> and lateral positions.<sup>7</sup> This clinical report documents the occurrence of VAE in an infant during a craniectomy in the supine position that resulted in dysrhythmias, hypotension, and cardiac arrest.

## REPORT OF A CASE

A 10-month-old infant born with multiple congenital anomalies was scheduled for a craniectomy to correct a severe anterior plagiocephaly. Two previous anesthetics for insertion of a ventriculoperitoneal shunt and for a hip arthrogram were uneventful. Anesthesia for this procedure was induced by the inhalation of halothane and maintained

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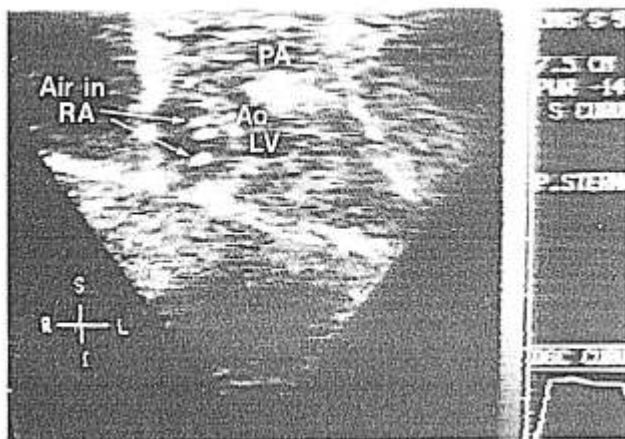


FIG. 1. Venous air in the right atrium.

with nitrous oxide, oxygen, and intravenous pancuronium and fentanyl. After the trachea was intubated and the child was positioned supine, the case proceeded uneventfully for 3 h until hypotension and dysrhythmias occurred during the frontal osteotomy. Hemodynamic stability followed the iv administration of atropine, vasopressors, and blood. The wound was closed rapidly and the child was transferred to the intensive care unit, weaned from control ventilation, and extubated 12 h later. The patient returned to the ward in good condition on the following day.

One week later, the patient was scheduled for completion of the procedure. Following an inhalation induction with halothane, nitrous oxide, and oxygen, the trachea was intubated orally, and the endotracheal tube was wired in place. Peripheral, external jugular, and arterial catheters were inserted. Anesthesia was maintained with nitrous oxide, oxygen, and iv pancuronium and fentanyl. Following the intubation of the trachea, a precordial Doppler (Medsonics) transducer was placed at the fourth intercostal space near the right sternal margin, and its position over the right heart confirmed.<sup>8</sup> Continuous two-dimensional echocardiography (ECHO) of all four chambers of the heart was carried out using a subxyphoid transducer position (Diasonics Cardiovue® 100). The patient was positioned supine with a small roll placed under the shoulders. The cervical spine was extended and the head was flexed so that the chin touched the chest wall at the sternal angle. After final

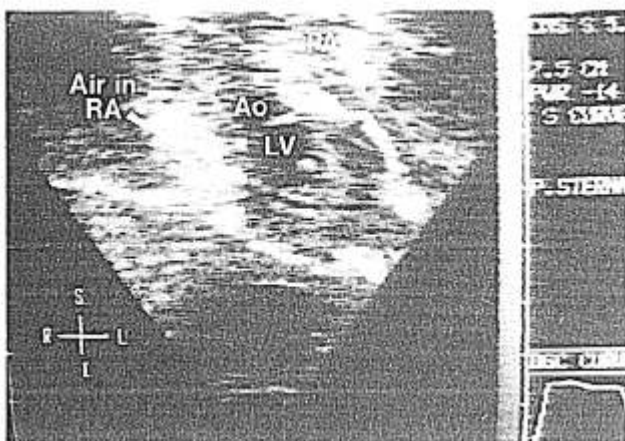


FIG. 2. Venous air opacifying the right atrium.

positioning, the surgical site lay approximately 10–15 cm above the level of the right atrium.

During the first h of surgery, the skull was exposed and prepared for completion of the frontal osteotomy. Extending the osteotomy laterally and posteriorly with the Midas Rex craniotome resulted in brisk bleeding. Almost immediately, atrial premature contractions were seen on the electrocardiogram and the Doppler was thought to pick up the characteristic sounds of VAE. On ECHO, clouds of reflectors, which were consistent with intravascular air, were seen entering the right atrium from the superior vena cava and exiting the pulmonary artery. The surgeon was notified of intravascular air, the osteotomy was quickly completed, the wound was flooded with saline, and all cut bone edges were promptly covered with bone wax. The head was taken out of extreme flexion, the shoulder roll was removed, and the wound was lowered to heart level. Nitrous oxide was discontinued, 100% oxygen was administered, and an unsuccessful attempt was made to aspirate air through the external jugular catheter. A brief period of hypotension and bradycardia was successfully treated with iv atropine, epinephrine, and crystalloid replacement. The echocardiographer recorded air entering and exiting the right heart for a total of approximately 3 min. On ECHO, the VAE appeared as a continuous faint trickle of reflectors (fig. 1) with occasional larger boluses (fig. 2) that opacified the right heart and immediately exited the pulmonary artery. No intravascular air was seen in the left heart at any time. Wound closure required 45 min and the patient remained hemodynamically stable until the last 15 min of closure, when refractory hypotension and bradycardia required an h of cardiopulmonary resuscitation before vital signs were restored. A brief period of hemodynamic instability followed transfer to the intensive care unit, but the patient was soon stabilized and weaned from inotropic and ventilatory support over the following days. Infected intracranial hematomas have been drained repeatedly and profound neurologic defects have persisted.

## DISCUSSION

This case demonstrates that VAE can occur in supine infants with catastrophic results. VAE is not considered to be a frequent complication of the supine position unless the surgical site is significantly elevated above the level of the heart.<sup>4</sup> Although this patient was positioned supine on the operating table, the addition of the shoulder roll and the extreme flexion position raised the frontal osteotomy site between 10 and 15 cm above the level of the heart. This slight elevation probably recreated the hemodynamics associated with sitting position craniectomies and led to the VAE. Infants have large heads in proportion to their age and weight, and their growing skulls are highly vascular. A major craniectomy in this child with a large, irregularly shaped head resulted in rapid hemorrhage and decreasing central venous pressure. If any pressure gradient developed between the right heart and the surgical site, air could have been entrained through open venous channels in freshly cut bone, resulting in VAE.

A high index of suspicion for VAE should be present during any pediatric neurosurgical procedure where a pressure gradient can exist between the surgical site and the right heart. Traditional strategies to avoid catastrophic VAE include volume loading to maintain central venous pressure, early detection, and prompt treatment.<sup>1,4</sup> In the

surgical field, application of bone wax and saline-soaked sponges to areas of hemorrhage may have reduced the potential entry sites for air, and lowering the head may have reduced the pressure gradient between the wound and the heart. We had infused crystalloid and blood products iv prior to beginning the osteotomy, but central venous pressure was not measured to confirm the effect of these infusions. However, as soon as the diagnosis of VAE was made by ECHO, steps were taken to stop the entry of room air and to prevent its hemodynamic consequences. The episode of intravascular air lasted about 3 min, and hemodynamic stability was quickly restored after a brief period of cardiovascular instability.

Precordial Doppler and continuous ECHO are accepted means of monitoring for VAE.<sup>9-11</sup> Doppler detects turbulence from intravascular air when positioned correctly over the right heart<sup>8</sup> and ECHO can directly visualize microbubbles of intravascular air as small as 10 mm in diameter.<sup>12</sup> In this case, correct positioning of the Doppler and the ECHO transducers was confirmed simultaneously by listening to the sounds of turbulence and by visualizing air bubbles following the iv administration of a small volume of agitated saline through either the jugular or the peripheral cannulae. When both transducers were used simultaneously, agitated saline could be detected easily by both monitors in spite of slight signal interference by the two transducers.

We believe that direct ECHO visualization of the heart can estimate the pattern of entrained air, as well as provide assessments about intracardiac shunting and therapy. It may be helpful in estimating the quantity of air as well. In this case, ECHO quickly ruled out right-to-left intracardiac shunting, documented the pattern of right-sided "bolus" and "trickle" air, and assessed the impact of our therapy on the infusion of air.

ECHO monitoring for VAE is occasionally criticized as being too sensitive. While ECHO can visualize microbubbles following iv injections and record spontaneous flow-related turbulence in the central circulation of infants,<sup>13</sup> we believe that ECHO is a valuable addition to standard VAE monitoring in children. In this case, it helped to confirm the diagnosis of VAE, which resulted in prompt treatment leading to restoration of hemodynamic stability. Unfortunately, the diagnosis and initial successful treatment of the VAE did not prevent bradycardia, hypotension, and cardiac arrest from occurring 45 min later at the end of the case. A new VAE probably could not have occurred after wound closure, and we believe any subsequent intravascular air would have had to result from late transcapillary migration of VAE that had been trapped in the pulmonary circulation.<sup>14,15</sup> While this mechanism has been implicated in some late-appearing paradoxical VAE,<sup>16</sup> other events may have led to the arrest. Inadequate volume replacement may have contrib-

uted to hypotension if persistent intracranial hemorrhage had been unnoticed in the wound or, alternatively, bradycardia leading to arrest could have resulted from direct cerebral compression due to hematoma.

We believe that ECHO should be used more often when VAE is suspected. Its expense and complexity, however, currently limit its widespread clinical application. The transesophageal ECHO may simplify the actual monitoring technique but will require quite small transducers to be applicable to infants. Whether the ECHO diagnosis of VAE in a pediatric neurosurgical population offers significantly more clinically relevant data than conventional monitoring, such as Doppler and end-tidal gas analysis, remains to be proven. Most importantly, we believe that strict attention to intravascular volume, careful monitoring for the detection of VAE, and aggressive treatment of the hemodynamic consequences of intravascular air should be standard practice in supine infants undergoing craniectomy, particularly when large osteotomies are planned.

In conclusion, we have presented a case of VAE resulting in cardiac arrest occurring during reconstructive cranial remodeling in an infant in the supine position. Subxiphoid transthoracic two-dimensional echocardiography was helpful in documenting the events leading to cardiac arrest.

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## Effects of Intravenously Administered Dyes on Pulse Oximetry Readings

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Pulse oximetry has emerged as an easily applied, non-invasive, and continuous monitor of arterial oxygenation in the perioperative period.<sup>1</sup> Various physiologic and environmental factors have been described that interfere with accurate determination of oxygen saturation ( $SO_2$ ). These include high-intensity light, patient movement, electrocautery, diminished perfusion, the administration of vasopressors, cardiopulmonary bypass, dyshemoglobinemias, and hypothermia.<sup>2</sup> We have observed a number of patients in whom iv-administered dyes appeared to be associated with abrupt decreases in pulse oximetry  $SO_2$  readings despite  $Pa_{O_2}$  in excess of 100 mmHg. A recent case report has also drawn attention to this phenomenon.<sup>3</sup> This study was undertaken to quantitate the magnitude and duration of these effects as measured by the Nellcor® N-100  $SO_2$  monitor in volunteers given one of three commonly used iv dyes.

### MATERIALS AND METHODS

Following Human Studies Committee permission and informed consent, 15 paid volunteers were studied. The subjects breathed room air and were supine with the head elevated 30°. Monitoring consisted of an automated blood pressure cuff with a 1-min cycle and a continuously displayed electrocardiogram. An iv infusion of 0.9% saline was established in a hand vein. Nellcor® pulse oximetry finger probes were applied to the index finger of the hand contralateral to the iv infusion site and to the right large

toe. These were connected to separate N-100 Nellcor® pulse oximetry monitors. When pulse oximetry readings appeared stable, one of three dyes was injected as a bolus into the briskly running iv line. The solutions injected were 5 ml of 1% methylene blue, 5 ml of 0.8% indigo carmine, or 5 ml of 0.25% indocyanine green. Pulse oximetry readings were recorded every 5 s for 5 min. The time from injection to the first noticeable decrease in  $SO_2$  readings (latency), the lowest  $SO_2$  reading (nadir), and the time required to return to baseline (duration) were noted for each subject from each of the two sensing locations.

Dyes were diluted 1:1000 with saline and placed in a spectrophotometer. Absorbance spectra of the three dyes were plotted on standard coordinates.

### RESULTS

Fifteen white subjects were studied, five with each of the three dyes. Dye administration was well tolerated. No change in heart rate or arterial blood pressure was observed in any subject following dye administration. Subjects given methylene blue, however, did report pain at the iv site on injection, which persisted for about 1 day. Baseline  $SO_2$  readings were 97 or greater in all subjects in both the toe and finger locations. Subject characteristics, latency, nadir, and duration are summarized in table 1 for each of the three dyes.

Of the three dyes, indigo carmine produced the fewest and smallest changes in  $SO_2$  readings. Decreases from baseline were observed in three of the five subjects given indigo carmine, but only in the toe location. The magnitude of the  $SO_2$  reading decreases were small following indigo carmine. The lowest  $SO_2$  reading observed in any subject was 92%. By contrast,  $SO_2$  reading decreases were observed in all subjects in both sensing locations following the administration of methylene blue. The median lowest  $SO_2$  reading (nadir) was 65%. The lowest  $SO_2$  reading observed following methylene blue was 1%. In subjects given

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