Venous embolization during sternotomy in children undergoing corrective heart surgery

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Gas embolism results from a negative pressure gradient between veins exposed to air and the central venous pressure.[1] The incidence varies according to the procedure, the position, and the detection method used. Venous air embolism (VAE) in cardiac surgery has been previously observed during central venous cannulation and while opening the heart chambers during cardiopulmonary bypass.[2] We now describe, for the first time, the detection of VAE by transesophageal echocardiography during sternotomy in children undergoing corrective heart surgery. In addition, we show that sternotomy with scissors significantly reduces the risk of embolization compared with using a saw.

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Patients and Methods

Patients

Twenty children scheduled for corrective heart surgery were enrolled. Patients with a previous sternotomy were excluded. Patients were randomly assigned to the saw or scissors group. Ten children who underwent sternotomy with a saw had a ventricular septal defect (n = 2), total anomalous pulmonary venous return (n = 1), tetralogy of Fallot (n = 1), truncus arteriosus (n = 1), mitral stenosis (n = 1), or double-outlet right ventricle (n = 1). The other 10 children who underwent sternotomy with scissors had an atrial septal defect (n = 2), ventricular septal defect (n = 2), tetralogy of Fallot (n = 2), total anomalous pulmonary venous return (n = 1), hypoplastic left heart syndrome (n = 1), transposition of the great arteries (n = 1), and cor triatriatum (n = 1).

Monitoring

Monitoring included electrocardiogram, pulse oximetry, end-tidal carbon dioxide, invasive arterial blood pressure, and central venous pressure. During sternotomy, patients were disconnected from the ventilator, and no fluids or medications were infused.

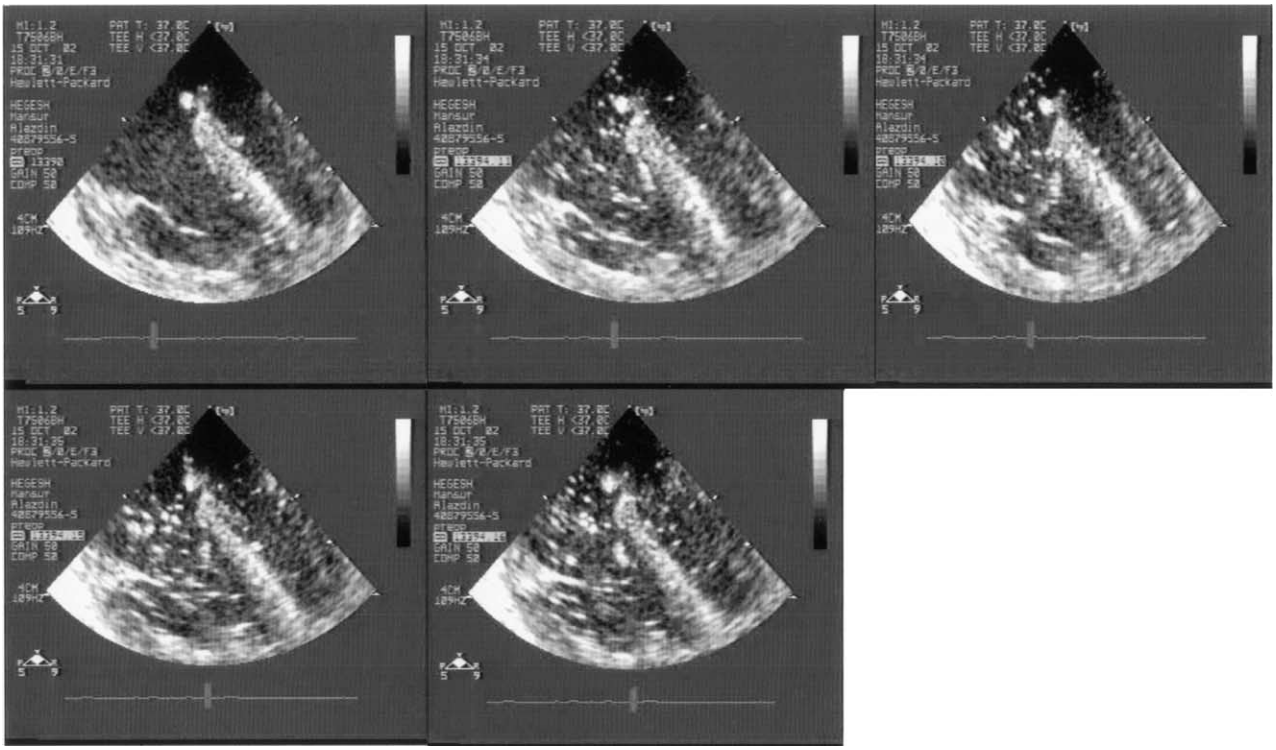

Figure 1. Transesophageal echocardiography images before and during sternotomy in a neonate with total anomalous pulmonary venous return.

Echocardiography

A 4-chamber view of the heart was obtained by a 5.0-MHz multiplane transesophageal echocardiography transducer (SONOS 5500; Hewlett-Packard, Andover, Mass). The transducer was positioned so that the right atrium was in the center of the screen. Data were recorded by a videotape.

Data Analysis

The number of VAEs was assessed qualitatively, per patient, by 3 pediatric cardiologists with clinical experience in intraoperative echocardiography. They were blinded to the method of sternotomy. The VAEs detected for each patient were defined on a scale of 0 to 3, where 0 indicated no targets, 1 indicated occasional targets, 2 indicated many targets, and 3 indicated targets filling the entire atrium.[2] The results of the 3 echocardiographic evaluations were averaged per patient, and a comparison between groups was performed by using the Mann-Whitney rank sum test.

Results

VAEs were detected in 14 (70%) patients. Most emboli were small (<2 mm) and appeared similar to the microbubbles produced by agitating saline with a small amount of air (Figure 1). The incidence was significantly higher ($P < .002$) when sternotomy was performed with a saw compared with scissors (Table 1). The peak number of emboli appeared approximately 5 seconds after sternotomy and returned to baseline at the end of the procedure. Six patients also had larger (>5 mm) emboli that appeared to be solid material. Passage of emboli to the left cardiac chambers was detected in 5 patients (25%) with a known right-to-left shunt and in whom sternotomy was performed with a saw. No significant hemodynamic changes or changes in end-tidal carbon dioxide or arterial saturation between preprocedure and postprocedure values were detected.

TABLE 1. Comparison of intracardiac emboli between children undergoing sternotomy with a saw versus scissors

Variable	Saw (n = 10)	Scissors (n = 10)
Intracardiac embol vs scale (mean ± SD)	1.90 ± 0.83*	0.41 ± 0.46
Median	2.0	0.33
Lower 95% CI	1.3	0.02
Upper 95% CI	2.49	0.80

CI, Confidence interval.
*$P < .002$; Mann-Whitney rank sum test.

Discussion

Children are less prone to VAE than adults, but they are more susceptible to the side effects, especially when a right-to-left shunt exists.[3] The incidence of VAE increases when a vein that cannot collapse is opened,[4] such as the cranial diploic veins. Other risk factors for VAE are large airway pressure variations, which were shown to decrease venous pressure to subatmospheric levels.[5] The same risk factors were present in our study population: opening of

the sternum veins bears some similarity to the opening of the cranial vault veins, and disconnecting the endotracheal tube just before sternotomy decreases airway pressure. Furthermore, 5 (25%) of our patients had a preexisting right-to-left shunt, again increasing the likelihood of clinically significant VAE. The fact that embolus incidence was higher with the saw compared with the scissors is not straightforward. It would seem that the saw would result in less compression of the bone marrow, thus being less traumatic. One may hypothesize that the vibration caused by the saw action induces microbubble formation such as in agitated saline. This hypothesis was tested by pressing the saw against the closed chest wall, thus testing the effects of the vibrations alone. No emboli were detected. Another explanation might be that the vibrations cause increased small amounts of air entrainment in the open vessels. This hypothesis has not been tested. In summary, our results suggest that VAE during sternotomy is a frequent occurrence and that the number of emboli is related to the method of sternotomy.

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