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# *Preoperative and Intraoperative Echocardiography to Detect Right-to-Left Shunt in Patients Undergoing Neurosurgical Procedures in the Sitting Position*

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**In patients undergoing neurosurgical procedures at high risk for venous air embolism (VAE), the presence of a right-to-left shunt adds an additional risk for paradoxical air embolism (PAE). Although this is a rare complication, it can have devastating results. The most common form of right-to-left shunt is a patent foramen ovale (PFO), which can be detected by contrast echocardiography. This study evaluates the efficacy of preoperative precordial and intraoperative transesophageal echocardiography (TEE) to detect right-to-left shunting in patients undergoing neurosurgical procedures while in the sitting position. In 101 patients precordial contrast echocardiography was performed prior to surgery. The Valsalva maneuver was utilized as a provocative maneuver to facilitate demonstration of right-to-left shunting. Fifty-one of these patients also had intraoperative TEE monitoring. Right-to-left shunting was demonstrated in only six of the 101 patients examined. Of these, four were detected by TEE. This is less than the expected incidence based on the known incidence of PFO in the general population. The usefulness of preoperative ECHO as a screening test for PFO in patients undergoing neurosurgical procedures is limited, but when a PFO is found, valuable information is acquired to help manage these patients. (Key words: Embolism: air. Heart: patent foramen ovale. Monitoring: echocardiography. Surgery: neurosurgery.)**

VENOUS AIR EMBOLISM (VAE) can occur in any patient undergoing an operative procedure in which the operative site is above the level of the heart and contains noncollapsible veins. In patients undergoing posterior fossa craniotomy while in the sitting position, the incidence of VAE is particularly high (45–50%).[1–3] Although the incidence of complications of VAE has decreased with the advent of more sensitive monitors for VAE and the resultant early detection and elimination of the source of air entry, significant morbidity from VAE continues to occur.

Paradoxical air embolism (PAE) can develop during an episode of VAE and may result in ischemic injury to tissues distal to the arterial air bubbles.[4] Although this is a rare complication, the results can be devastating. Identification of intracardiac defects by preoperative echocardiography has been advocated to reduce the risk of major morbidity and mortality from air embolism in patients at high risk for VAE, such as those undergoing surgical procedures while in the sitting position.[5] The most common defect associated with PAE has been found to be the patent foramen ovale (PFO), which can be detected with contrast echocardiography.[6,7] This study was undertaken to prospectively evaluate the efficacy of preoperative contrast echocardiography to detect intracardiac defects that could result in PAE during VAE.

## Methods

One hundred one patients scheduled for neurosurgical procedures while in the sitting position were evaluated with preoperative precordial echocardiography on the evening before or the morning of surgery. All examinations were performed by experienced echocardiographers. A standard two-dimensional precordial echocardiogram was done in all patients, viewing the heart from multiple tomographic positions, as previously described.[8] Special attention was given to visualizing the atrial septum from the parasternal and subcostal views. From the two-dimensional examination, an echocardiographic window was selected that best displayed both left- and right-sided chambers. During continuous imaging from this window, agitated indocyanine green dye was then injected and flushed through a peripheral vein during normal spontaneous respiration. Indocyanine green dye has the advantage over agitated saline in that it creates a saponification effect. This stabilizes the microbubbles so that there are a greater number of bubbles that reach the cardiac chambers after a peripheral injection. This resulted in prompt opacification of the right atrium and right ventricle from the microbubbles in the indocyanine green dye solution.[9] The left chambers were observed for appearance of microbubbles. The patients were then instructed to perform a Valsalva maneuver. Careful attention was made to assure that there was elevation of the venous pressure and a reflex tachycardia during the strain phase of the maneuver. Two additional injections of indocyanine green dye were performed during the release phase of the Valsalva maneuver and the left-sided chambers were again observed for the presence of microbubbles.[10]

In addition, 51 of these patients also had intraoperative evaluation with transesophageal echocardiography (TEE) by anesthesiologists experienced with the technique.

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Modified four-chamber views of the heart were obtained with a 3.5 MHz Diasonics® esophageal echocardiographic probe mounted on a 5-mm bronchoscope body and connected to a 3400 Diasonics echocardiographic machine. The TEE probe was inserted following induction of anesthesia. A multiorifice right atrial–superior vena caval catheter was inserted using electrocardiographic control. Ten milliliters of agitated saline with microbubbles was injected through the right atrial catheter at end-expiration during intermittent positive pressure ventilation with zero end-expiratory pressure. This resulted in prompt opacification of the right heart chambers. The left heart was observed for evidence of paradoxical passage of microbubbles. The injection was repeated with 20 cm water positive end-expiratory pressure just as the positive end-expiratory pressure (PEEP) was released. TEE was also used intraoperatively during any episode of air embolism to detect evidence of PAE. All patients were routinely monitored for VAE with precordial Doppler.

## Results

Preoperative precordial echocardiography detected no instances of right-to-left shunting during spontaneous respiration. There was right-to-left shunting during the Valsalva maneuver in six of 101 patients (6%). No visible intracardiac shunts were detected by two-dimensional imaging. All patients in whom right-to-left shunting was detected were monitored with TEE intraoperatively. Of these six patients, four underwent posterior fossa craniotomy while in the horizontal position, one underwent cervical laminectomy while in the sitting position, and one underwent cervical laminectomy while prone. In four of the six patients with preoperative detection of right-to-left shunting, right-to-left shunting was also detected with TEE. In no patient did TEE examination detect right-to-left shunting when a precordial examination failed to do so. In one patient preoperative precordial echocardiography and TEE with injection of agitated saline with and without PEEP detected no right-to-left shunting, but during an episode of VAE intraoperatively PAE was observed on TEE.

No patient developed clinical signs of PAE in the form of cardiac dysrhythmias, cardiac ischemia, visualization of cerebral arterial air bubbles, or unexpected postoperative neurologic deficits. There were no adverse effects of either preoperative precordial echocardiography or intraoperative TEE. Clinical management was altered in all six patients in whom right-to-left shunting was detected preoperatively either by change in surgical position to one with a lower incidence of VAE or extreme surgical caution intraoperatively to prevent or eliminate any potential sources of VAE. None of the patients with preoperative detection of right-to-left shunting had VAE detected intraoperatively by precordial Doppler.

## Discussion

PAE is a rare complication in patients undergoing posterior fossa surgery while in the sitting position, but when it occurs, the results can be devastating.[4] In patients with no obvious congenital cardiac defects, the occurrence of PAE has been postulated to be due to the presence of a PFO. Because injection of echocardiographic contrast, such as indocyanine green dye, can accurately detect right-to-left shunting,[11] it has been suggested that PFO may be diagnosed with green dye injection and two-dimensional echocardiography during provocative maneuvers, such as the Valsalva maneuver, which transiently reverses the normal left atrial to right atrial pressure gradient.[5]

PFO has been demonstrated to occur in 25–35% of patients with no history of cardiac disease in autopsy studies.[12,13] Series investigating PFO by echocardiographic examination in otherwise healthy patients report an incidence of PFO ranging from 10% to 18%.[6,11] Preoperative echocardiography in evaluation of patients to undergo surgical procedures in the sitting position revealed a 10% detection rate of probable PFO.[14] In another series reporting the results of echocardiography in patients with known PFO (from angiography), echocardiography demonstrated only 64% of the patients with PFO using both Valsalva maneuver and cough to facilitate right-to-left shunting.[15] These results suggest that even in the hands of cardiologists experienced in echocardiography, preoperative echocardiography will reliably detect only a portion of patients with a PFO. This was confirmed in the present study in which only 6% of patients had right-to-left shunting detected preoperatively. In addition, there was one patient who demonstrated no evidence of right-to-left shunting on precordial or TEE with provocative maneuvers and was found to have spontaneous left-sided air embolism during VAE at a later time. Perhaps the Valsalva maneuver to increase right heart pressures relative to left heart pressures does not adequately mimic the clinical circumstances that can lead to the occurrence of PAE during VAE (increases in pulmonary vascular resistance and right heart pressure).

Therefore, although preoperative detection of a PFO certainly indicates that the patient is at risk for PAE during surgical procedures with a significant risk of VAE, the failure to detect a PFO does not eliminate the possibility that the patient is at risk for developing PAE. Based on the reported incidence of PFO (25–35%), it is likely that several patients in our series had PFO and normal preoperative echocardiography. A high false-negative rate (low sensitivity) limits the usefulness of preoperative echocardiography to predict risk for PAE. When a right-to-left shunt is detected, the specificity is likely high.

The best recommendations for management of patients undergoing procedures with risk for VAE continue to include careful monitoring for VAE and prompt elimi-

nation of the source of entrained air. The most advanced technology for monitoring for PAE and detection of PFO is TEE equipped with two-dimensional–pulse wave Doppler and color flow imaging (CFI). Although the most sensitive clinical monitor for PAE is intraoperative TEE, to date there is no clinical standard for monitoring for PAE. We predict that because TEE with pulse wave Doppler is more sensitive than precordial Doppler for detection of VAE[16] and CFI is likely to improve detection of PFO, the gold standard for monitoring for intraoperative VAE and PAE will be a versatile TEE unit (two-dimensional–pulse wave Doppler CFI).

Presently available preoperative echocardiography allows identification of some but not most patients with PFO. It is costly in time, effort, and money but is noninvasive and relatively risk-free. These data suggest that at present preoperative echocardiography has a limited sensitivity for PFO detection, but it may provide unique information that both the anesthesiologist and surgeon can utilize in discussion and planning of the operative position and appropriate monitoring. The use of intraoperative TEE is advantageous for either diagnosing a PFO after induction of anesthesia (although there is a significant risk of a false-negative examination) or to detect PAE should it occur intraoperatively. In our practice we do not believe that the advantage of the preoperative echocardiography is at present worth the added expense. With the utilization of intraoperative TEE we may choose to alter the patient's position before the operation is begun if a PFO is detected after induction of anesthesia. In addition, we can make appropriate clinical decisions if PAE is diagnosed during the operative procedure. The presence of normal echocardiography preoperatively or intraoperatively does not eliminate the risk for PAE,[17] but the sensitivity of TEE to PAE is high so that the likelihood of clinically significant PAE that does not appear on TEE is remote.

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