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Identification of Patent Foramen Ovale during Sitting Position Craniotomy by Transesophageal Echocardiography with Positive Airway Pressure

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The clinical problem of venous air embolism during upright neurosurgical procedures remains a serious one. Pulmonary vascular obstruction may ensue with cardiovascular collapse or pulmonary insufficiency. Paradoxic air embolism may occur with devastating neurologic consequences.[1]

The use of the precordial Doppler in the detection of venous air embolism was an important clinical step in improvement in the diagnosis, allowing early treatment.[2] The use of the right heart catheter and capnograph have also added additional information regarding venous air embolism in clinical practice. None of these methods, however, detects paradoxic air embolism. The clinician might be acutely aware of the occurrence of venous air embolism and treat it vigorously yet not know whether air has crossed into the arterial circulation, a clinically important piece of information.

The development of contrast M-mode echocardiography introduced the capability to visualize air microbubbles in the left cardiac chambers.[3] With the further technologic advance of 2-D echocardiography, and then phased array 2-D transesophageal echocardiography (TEE), it became theoretically and clinically possible to detect venous air embolism and paradoxic air embolism intraoperatively.

METHODS

The present study attempts to combine TEE and positive airway pressure to detect those patients at risk for paradoxic embolism due to patent foramen ovale or occult atrial defects. Twenty adult patients undergoing elective sitting position neurosurgical procedures were studied. Anesthetic management included induction with sodium pentothal, maintenance with isoflurane 0.25–1%, mechanical ventilation (PE_{CO_2} 22–23), and nondepolarizing muscle relaxants as clinically indicated. Monitoring consisted of transesophageal echocardiography, direct arterial and right atrial pressure measurements, electrocardiogram, precordial Doppler, end-tidal p_{CO_2} and pN_2. A 3.5 MHz transesophageal probe (Diasonics) was placed after induction of anesthesia and interfaced to a two-dimensional phased array echocardiographic machine (3400 Diasonics®). A modified four-chamber and modified long-axis view were utilized to allow optimal visualization of the left and right atrium, the interatrial septum, and the left ventricular outflow tract.

After the patients were upright and stable, agitated saline was injected through the right atrial catheter during continuous two-dimensional echocardiographic visualization of the cardiac chambers. Examinations were recorded on ¾″ video tape and reviewed by an independent observer. All examinations were performed twice at zero end-expiratory pressure (ZEEP) and twice at 20 cmH_2O positive airway pressure (held for 5 s). Injections were made during the last seconds before release of positive airway pressure with observational emphasis on the release phase of airway pressure and systole. Control sitting, incision, and hourly examinations for 3 h were performed.

RESULTS

In three of the 20 patients studied, there was evidence of right to left shunting at the atrial level, presumably due to a probe patent foramen ovale. Each circumstance of detection was somewhat different.

Patient 1 was operated upon for an Arnold-Chiari malformation. Echocardiographic contrast media injection at ZEEP at 20 cm positive airway pressure failed to demonstrate right to left passage to injectate until 3 h after incision. At that test point, paradoxic movement of the contrast media could be seen only with positive airway pressure but not with ZEEP. Air embolism in the right heart chambers was detectable by Doppler, capnography, and TEE 12 min after the 3-h test injection and was not detected in the left heart chambers on

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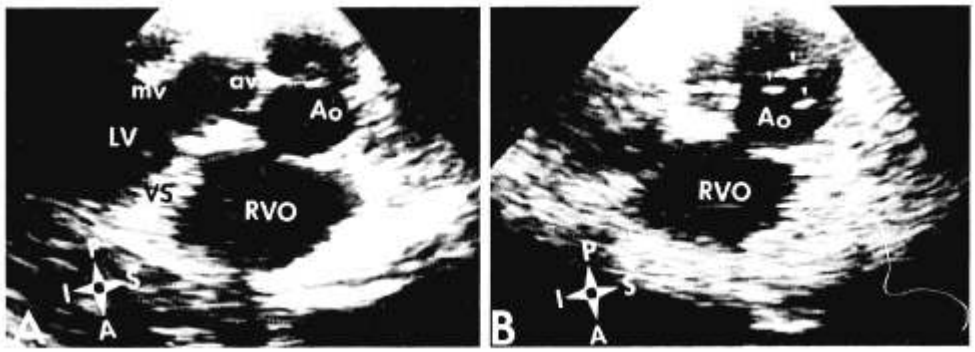

FIG. 1. Modified long-axis view as imaged by the transesophageal transducer. The left ventricular outflow tract is well visualized. *A.* Before injection of contrast. *B.* After injection of contrast. Contrast bubbles (*arrows*) are seen in the aorta. LV = left ventricle; Ao = aorta; AV = aortic valve; MV = mitral valve; VS = ventricular septum; RVO = right ventricular outflow; S = superior; I = inferior; P = posterior; A = anterior.

TEE. The surgical procedure was completed, and no postoperative sequelae occurred.

Patient 2 underwent suboccipital craniotomy for arteriovenous malformation. None of the agitated saline passed to the left heart for up to 2 h. The patient had four episodes of air embolism, the third of which was associated with a Doppler change, RA catheter air aspiration, decreased expired p_{CO_2} and increased pN_2, and a 20-mm decrease in arterial blood pressure at 1 h. Paradoxic air embolism was seen on ECHO in that episode only. Surgery was completed without difficulty, and no postoperative sequelae occurred.

Patient 3 was prepared for a cervical laminectomy. In the control upright injection, right to left passage of injectate was observed with positive airway pressure but not a ZEEP (fig. 1). It could not be repeated on two subsequent injections at positive airway pressure. The surgery therefore was performed in the prone position, and no paradoxic contrast passage could be identified for the remainder of the procedure. Precordial two dimensional echocardiographic examination 6 days after operation, utilizing iv injection of indocyanin green dye, revealed evidence of right to left shunting at the atrial level during a Valsalva maneuver.

DISCUSSION

In the patient with an intact atrial septum by echocardiography, the occurrence of right to left shunting at the atrial level is presumably due to a patent foramen ovale.[5] The preoperative identification of the patient with a patent foramen would help the surgeon and anesthesiologist assess the relative risks and benefits of conducting the procedure in the sitting position.[6] The use of precordial echocardiography and Valsalva maneuver to identify right to left shunting at the atrial level in healthy volunteers has been reported.[5]

In patients 1 and 3 this shunt could be found intraoperatively. However, patient 2 demonstrates four points. Even with positive airway pressure it is possible to miss a probable patent foramen ovale that is present. In addition, not all patients with a patent foramen ovale will have paradoxic passage of air, should venous air embolism occur. Hemodynamics of the right circulation in some patients may be altered sufficiently by air embolism to cause shunting through an otherwise functionally closed patent foramen ovale. When paradoxic air embolism is identified on TEE, postoperative sequelae still may not occur, depending on the volume of air that crosses to the arterial circulation and its ultimate destination.

The expected incidence of patent foramen ovale is 20–30%.[7] Precordial contrast two-dimensional echocardiography during Valsalva maneuver in healthy volunteers revealed an 18% incidence of right to left shunting at the atrial level.[5] In the present study, two patients (10%) showed evidence of right to left shunting at atrial level on contrast transesophageal echocardiography with positive airway pressure. One patient with paradoxic air embolism likely had a patent foramen ovale that was missed by TEE and PAP.

There is evidence that the usual left to right atrial pressure gradient may reverse after 1 h in the surgical upright position.[8] By injecting hourly, it may be possible to demonstrate reversal of this gradient in the patient with a probable patent foramen ovale, as in patient 1.

If one considers the incidence of probe patent foramen ovale (20–30%),[7] air embolism (40%),[2] and incidence of right atrial pressure exceeding left (50%),[8] the estimated risk of paradoxic air embolism in the sitting position is about 5%.

The thrust of acceptance of the precordial Doppler as a monitor for air embolism in the 1970s was its sensitivity. Early diagnosis should enable early treatment and reduce morbidity. Perhaps the same logic will apply to the 2-D transesophageal echocardiography. Early detection of probe patent foramen ovale and/or minute quantities of systemic arterial air should enable early treatment to prevent morbidity.

The identification of paradoxic air embolism intraoperatively could modify patient care in two ways. The decision as to when to lower a patient from the sitting

position is a clinical one, usually based on near cardiovascular collapse due to air embolism. The decision also may rarely be made upon visualizing air in the arteries of the brain. When paradoxic air is noted, it would seem reasonable that air entry must be stopped immediately by the surgeon or that the patient be lowered immediately to prevent further air entry. Secondly, if a patient sustained paradoxic air embolism by TEE and awoke with a neurologic deficit clearly not due to the surgical procedure, one might very strongly consider the use of a hyperbaric chamber immediately if possible to try to reverse that deficit.

In summary, the use of positive airway pressure (present study) and Valsalva[5] did aid in the transesophageal and precordial ECHO identification of probable patent foramen ovale in the anesthetized patient to allow detection where ZEEP failed. The method does fail to detect a patent foramen ovale at some rate that can only be determined by a much larger series. Intraoperative identification of patent foramen ovale is a step nearer to preoperative identification as an important part of the evaluation of a patient for surgery in the sitting position.

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Detection of Air Emboli in the Left Heart by M-Mode Transesophageal Echocardiography Following Cardiopulmonary Bypass

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Despite the enormous improvements in surgical techniques and extracorporeal apparatus, air embolism still occurs during cardiac surgery. Echocardiography can be used as a device to detect air during cardiac surgery.[1] We have been using M-mode transesophageal echocardiography (TEE) as a monitor of the heart during cardiac surgery[2] and have often observed bizarre echo contrast in the left side of the heart. Similar appearances have been seen in the right side of the heart after bolus administration of drugs via the central venous route. Recent studies demonstrated that microbubbles of gas injected with liquid solutions are the source of such ultrasonic contrast.[3] Furthermore, Furuya *et al.*[4] reported that air emboli can be successfully detected by TEE in both the right and left sides of the heart. We report here the incidence of appearance of air emboli by echocardiography after cardiopulmonary bypass (CPB) in patients undergoing either open cardiotomy or coronary artery bypass grafting (CABG). Postoperative complications were also studied prospectively and correlated with the degree of air emboli echograms seen after CPB.

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Materials and Methods

Fifteen patients who underwent open cardiotomy with or without CABG and 18 patients who underwent