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Air Embolism in Upright Neurosurgical Patients: Detection and Localization by Two-dimensional Transesophageal Echocardiography

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The clinical use of M-mode contrast echocardiography, a technique in which saline containing microbubbles of gas injected iv is utilized as an echocardiographic contrast medium, was first described by Seward *et al.*[1] in 1975. With new technology, transesophageal echocardiography (TEE) utilizing M-mode transducers have been designed to detect air embolism in neurosurgical patients.[2] With the development of 2-dimensional (2-D) sector echo transducers, a large tomographic field of view could be obtained which permits better appreciation of anatomic relationships. The heart is visualized in a "bread-slice tomographic plane" rather than the "ice-pick" view of the M-mode echo.

METHODS

This work describes the use of a prototype, 3.5-MHz transesophageal echocardiographic (TEE) probe (Diasonic) interfaced with a 3400 Diasonics phased array sector echo instrument. With informed consent and after the induction of general anesthesia, the probe was inserted in 15 patients undergoing suboccipital craniotomy in the sitting position. Precordial Doppler and right atrial catheter were used in all patients. The echo image was monitored on a video screen and recorded on ¾-inch video tape for real time and slow motion independent review by an experienced cardiologist (JBS). An image at just below the level of the aortic valve which displayed right and left atrial cavities was utilized (fig. 1). The forced injection of saline (echo contrast medium) was used to determine Doppler position and chamber visualization on echo. Saline injection was repeated hourly during surgery. This study was designed not to replace conventional monitoring but to test the comparative sensitivity of 2-D TEE in the neurosurgical environment. Thus, once in position, the TEE was turned off and precordial Doppler was used to monitor for the presence of an air embolism. During episodes of detectable air embolism, the echo probe was activated to confirm and localize air to right and/or left heart chambers. A single bubble of air can be detected by 2-D echocardiography.[1,3]

RESULTS

In nine of 15 cases, the precordial Doppler detected air. Every TEE easily visualized and localized the air. In two cases where precordial detection was questionable, TEE confidently verified air. The most important finding

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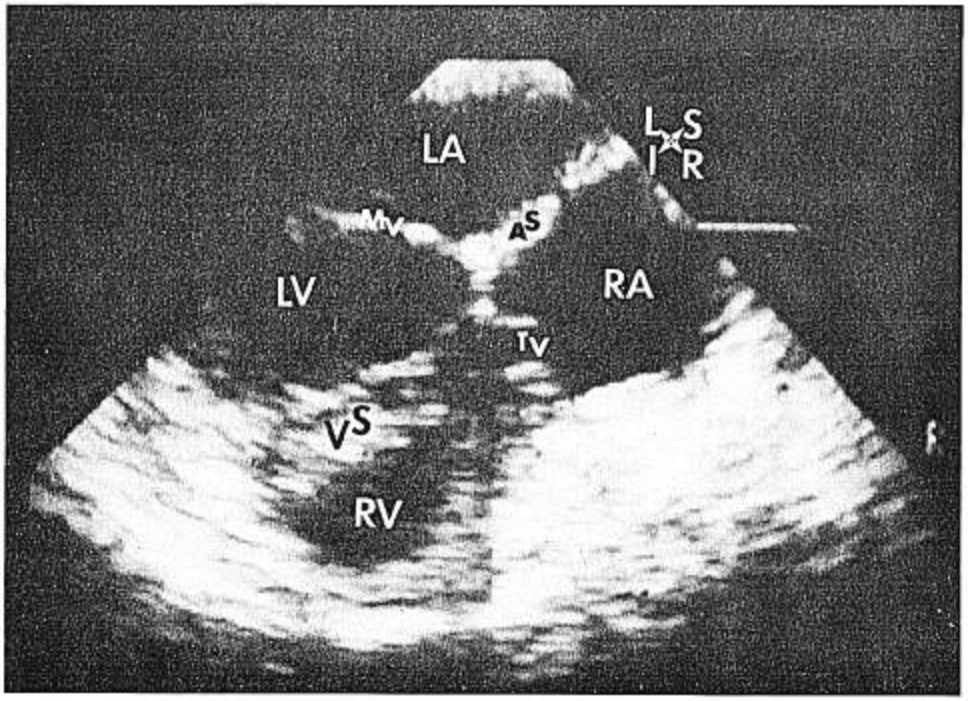

FIG. 1. Normal 4-chamber cardiac view as imaged by the transesophageal transducer. All four cardiac chambers are imaged simultaneously from the posterio-inferior surface of the heart. RV = right ventricle; LV = left ventricle; VS = ventricular septum; TV = tricuspid valve; MV = mitrial valve; LA = left atrium; RA = right atrium; and AS = atrial septum, [L = left, R = right, S = septum (basal), I = inferior (spinal) cardiac orientation].

occurred during a significant episode of venous air embolism where TEE detected air crossing from right atrium to left atrium with subsequent opacification of the left ventricle and aorta (fig. 2). Precordial Doppler could not localize the air to a specific chamber. Air was aspirated from the right atrial catheter. The patient with paradoxical air embolism did not suffer a neurologic sequelae. In no case did the test injectate appear in the left heart chambers, even in the patient with paradoxical air embolism. The right atrial catheter could be visualized in six of the 15 cases. Air was aspirated from the catheter in three of the nine cases with Doppler detected venous air embolism.

DISCUSSION

Accurate detection and localization of air embolism is important during neurosurgery. The thrust of current research has been toward the detection and prevention of paradoxical air embolism.[2,3] The passage of embolized air from the venous to the arterial circulation probably

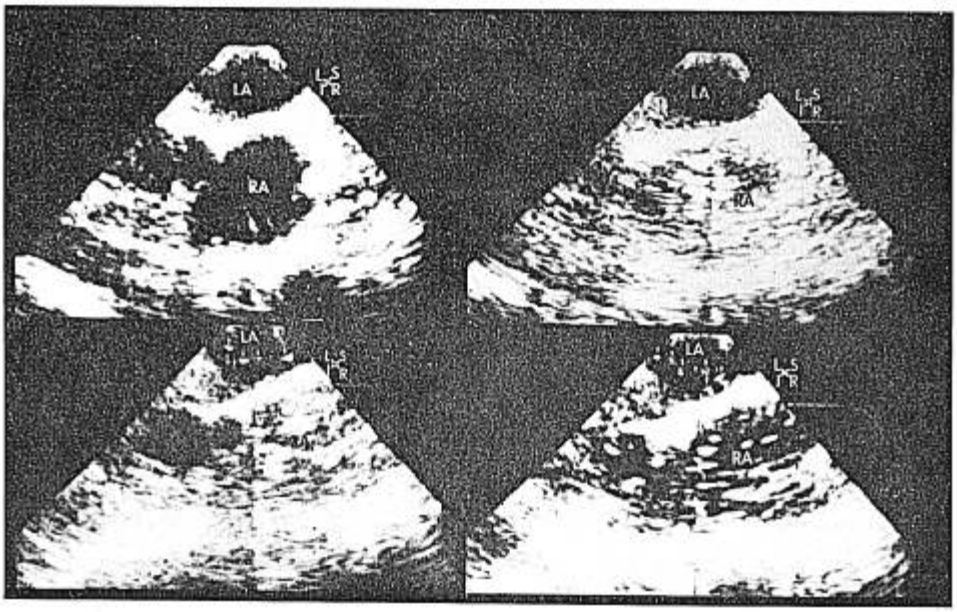

FIG. 2. Paradoxical air as noted by transesophageal echocardiography. *Upper left:* normal; *upper right:* air in right atrium; *lower left:* air in left atrium, right atrium nearly opacified; *lower right:* more air in left and right atrium.

occurs through a patent foramen ovale. The relationship of right and left atrial pressures is thus an important consideration in patients at risk for venous air embolism. The normal left atrial to right atrial pressure gradient has been reported to reverse after approximately one hour of surgery in the upright position.[4] In our study, repeated injections into the right atrium failed to demonstrate passage of injectate into the left atrium (LA) or aorta even after four hours of surgery in the upright position. A patent foramen ovale may not have been present or the described positive right to left atrial gradient was not present or sufficient enough to cause paradoxical movement of the injectate. The usefulness of contrast TEE in intraoperative detection of patent foramen ovale remains to be demonstrated. We are presently studying the combined use of PEEP and TEE in identification of patent foramen ovale.

One patient in this study developed documented paradoxical air embolism without neurologic sequelae. While no contrast was seen in the left atrium of this patient, air could be identified in the LA during entry of the venous air embolus. This suggests that some patients may suffer paradoxical air embolism without neurologic sequelae. We could surmise that the difference between asymptomatic and symptomatic arterial air embolism might simply be one of the quantity of air that crosses to the arterial circulation. Thus, early detection of left-sided cardiac air might be more important than we can yet prove in preventing poor neurologic outcome. Since the incidence of probe patent foramen ovale is 25–30% and air embolism 20–40%[4] there is a potential incidence of right-to-left embolism in the upright neurosurgical patient of at least 5%. This is consistent with our preliminary observations in 15 patients. The incidence of Doppler detected air in these patients undergoing suboccipital craniotomy in this study was nine of 15 cases (60%). This is somewhat higher than reported in previous studies at the same institution (40%),[5,6] but our sample size is quite small.

The ECHO and Doppler ultrasound units are similar in their technical features and can be expected to have similar sensitivities. The best study of comparative sensitivity of the two methods requires simultaneous use of both devices and a quantitative measure of air injected until detection. Neither of these is possible at this time in humans. Doppler and TEE interfere with each other by ultrasound "crosstalk." Quantitative injection of venous air in humans is unacceptable. All cases of Doppler detected air were visualized by TEE. In two cases the Doppler was questionable and TEE visualized the air embolus. Statistically no difference could be shown between the two methods. Again, the sample size is small, however.

The technical features of this prototype transducer which can be expected to improve include reduced transducer size and enhanced image resolution. With these changes performance and clinical usefulness of TEE also will improve. At present there is no other clinical device that provides direct visualization of all cardiac chambers or their contents. Transesophageal 2-D echo brings this technology within the realm of the operating room.

We conclude that in this study, 2-D TEE is likely as sensitive as precordial Doppler in detecting air embolism. The device can be utilized in the operating room with minimal delay in case preparation. Confident and reproducible cardiac chamber visualization can be easily obtained. Most importantly, paradoxical air embolism in the upright neurosurgical patient can be recognized quickly and localized utilizing 2-D TEE transesophageal echocardiography.

ADDENDUM

Since the completion of this study two patients suffered unilateral vocal cord paralysis following the use of the TEE in upright surgery. Both have recovered. It is possible that the rigidity of the gastroscope body of the TEE combined with neck flexion and endotracheal intubation could be responsible. We have withheld further use of the device in this circumstance while engineering and remanufacturing improvements correct this stiffness problem.

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