Anesthesiology
74:212–216, 1991

Intraoperative Detection of Patent Foramen Ovale by Transesophageal Echocardiography

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This study reports the intraoperative use of contrast and Doppler echocardiography techniques to diagnose patent foramen ovale (PFO). Fifty patients without known atrial septal defects undergoing elective cardiovascular surgery were studied. A 5-MHz esophageal echocardiographic probe was used to image the fossa ovalis (FO) and 10 ml agitated saline was injected into the right atrium during apnea. Echocardiographic contrast was then injected during end-inspiration at 20-cmH_2O airway pressure. When opacification of the right atrium was complete, the airway pressure was released. During these maneuvers, color and pulsed-wave Doppler interrogation of the atrial septum were also performed. Right-to-left passage of saline contrast across the interatrial septum was seen in 11 of 50 patients (22%). Doppler echocardiography demonstrated a PFO in 2 patients without contrast evidence of shunting. Thus, the combination of contrast and Doppler echocardiography identified a 26% (13 of 50) prevalence of PFO, approximating the previously reported autopsy rate of 25%. These contrast and Doppler techniques may be useful in detecting patients at risk for paradoxical emboli and in identifying candidates for closure of the PFO. (Key words: Embolism: paradoxical. Heart: patent foramen ovale; atrial septal defect. Measurement technique: transesophageal echocardiography; contrast.)

AUTOPSY STUDIES have shown that patent foramen ovale (PFO) exists in approximately 25% of the population.[1] These PFOs are a potential source of right-to-left shunts through which air or particulate emboli may pass (paradoxical emboli). It has been shown that these paradoxical emboli are responsible for strokes in anesthetized and ambulatory patients.[2,3] Previous attempts to diagnose PFO by contrast echocardiography have yielded prevalence rates of only 6–10%.[3,4] Furthermore, there are several reports of patients having documented intraoperative paradoxical air emboli despite negative preoperative echocardiographic screening.[4,5,6] These low detection rates and the occurrence of false-negative results have discouraged the use of the technique as a screening modality for use prior to operations that may pose a significant risk of air or particulate emboli. This study reports the intraoperative use of modified contrast echocardiographic and pulsed-wave and color Doppler echocardiographic techniques to identify interatrial shunts through presumed PFOs.

Materials and Methods

The protocol was approved by the institutional review board and written informed consent was obtained from 50 patients undergoing elective cardiovascular surgery (36 coronary revascularization, 6 valve replacements, 3 combined coronary revascularization/valve replacements, 1 ventricular aneurysm, 1 abdominal aortic aneurysm, 1 defibrillator implant, 1 pericardial drainage, and 1 mapping and ablation of an accessory pathway). There were 35 males and 15 females with a mean age of 62 ± 13 yr. Patients with known atrial septal defects, embolic neurologic deficits, or esophageal disease were excluded from the study. Each patient had radial and pulmonary arterial catheters inserted before the induction of anesthesia. All of the echocardiographic examinations were performed by experienced echocardiographers (SK, EL).

After tracheal intubation a 5-MHz transesophageal echocardiographic probe was inserted approximately 30 cm and connected to a Hewlett-Packard (Andover, MA) Sonos 1000 (64 element probe), an Acuson (Mountain View, CA) model 128 (64 element probe), or an American Technology Laboratories (Bothell, WA) Ultramark 9 (48 element probe) ultrasonograph. The probe was positioned to obtain a view of the right and left atria, centering on the fossa ovalis (FO) and with the interatrial septum in its narrowest cut.[7] In this view, the interatrial septum is perpendicular to the ultrasound beam, and flow across the septum is parallel to the ultrasound beam. This orientation facilitates Doppler interrogation (fig. 1). To optimize sensitivity for detecting intravascular contrast, extraneous echoes from the blood pool (in the absence of contrast injection) were minimized by adjusting the transmitted ultrasound power, signal gain (time gain compensation ramp), and gray-scale compression controls. These settings were held constant throughout the study period. The depth of field was adjusted to maximally magnify the region of interest.

Prior to sternotomy and during continuous hemodynamic recording of the pressure tracings, 10 ml saline was vigorously agitated without the addition of air by ex-

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Received from the Department of Anesthesiology and the Department of Medicine, Loyola University Medical Center, Maywood, Illinois. Accepted for publication September 29, 1990. Presented in part at the annual meeting of the Society of Cardiovascular Anesthesiologists, May 1990.

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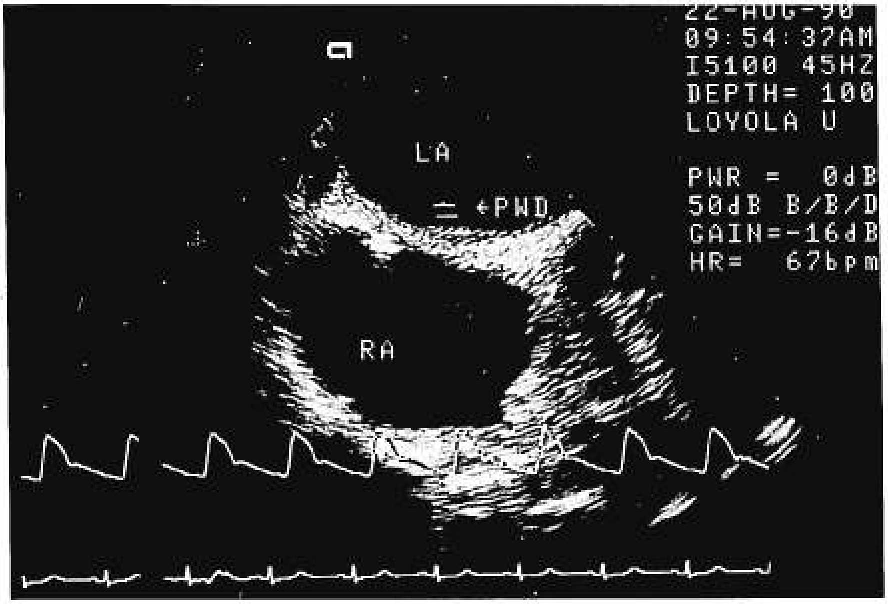

FIG. 1. Biatrial transesophageal echocardiographic view. LA = left atrium; RA = right atrium; PWD = pulsed-wave Doppler sample volume located on the left atrial side of the fossa ovalis.

changing it between two syringes interconnected by stopcocks, and then was rapidly injected into the right atrium during a brief period of apnea at end-expiration. Injection was deemed adequate only if the right atrium was completely opacified by the contrast. Opacification always was achieved with a single injection, although occasionally three or four attempts were required. Identically produced agitated saline was then injected at end-inspiration with 20-cmH_2O positive airway pressure. When more than one injection was necessary, the subsequent injection was performed after the atrium was clear of contrast from the prior injections. When opacification of the right atrium was complete, the airway pressure was released. If during either maneuver there appeared to be shunting that could confirmed by two observers, the injection was repeated. After the contrast studies, with the FO and the interatrial septum perpendicular to the ultrasound beam, the entire interatrial septum was imaged by color flow Doppler to detect interatrial shunting. In addition, both the right and left atrial sides of the interatrial septum were systematically interrogated with a pulsed-wave Doppler sample volume guided by the underlying color flow Doppler image.

Results

Two-dimensional Echocardiography

High-quality two-dimensional echocardiograms were obtained in all of the patients, and none of the patients had a visible discontinuity of the atrial septum. In eight cases the atrial septum was explored during surgical exposure (seven mitral valve replacements and one accessory pathway mapping), and in one case (coronary revascularization), the septum was explored to close a PFO that had been detected by echocardiography. In all of these cases, the echocardiographic determination of patency or nonpatency of the foramen ovale was found to be correct. None of the patients developed a perioperative neurologic deficit, and there were no complications attributable to the study.

Contrast Echocardiography

Complete opacification of the right atrium was obtained in all of the patients. During apnea, 5 patients demonstrated right-to-left shunting of contrast. After release of the positive airway pressure, right-to-left shunting occurred not only in all of the patients in whom shunting occurred during apnea, but also in an additional 6 patients (fig. 2). Thus a total of 11 of 50 (22%) patients had contrast echocardiographic evidence of interatrial shunting.

Doppler Echocardiography

Color flow Doppler detected right-to-left shunting in 3 patients and left to right shunting in 1 patient. These findings were confirmed by pulsed-wave Doppler echocardiography. Two of the patients with Doppler evidence of right-to-left shunting also had contrast evidence of PFO. However, the other 2 patients did not have contrast evidence of shunting. In 1 of these 2 patients, color flow mapping revealed a right-to-left shunt, and in the other it revealed a left-to-right shunt. Combining the Doppler and contrast echocardiographic data reveals that 13 of 50 (26%) patients had evidence of interatrial shunting. The echocardiographic characteristics of the 13 patients with a PFO are shown in table 1.

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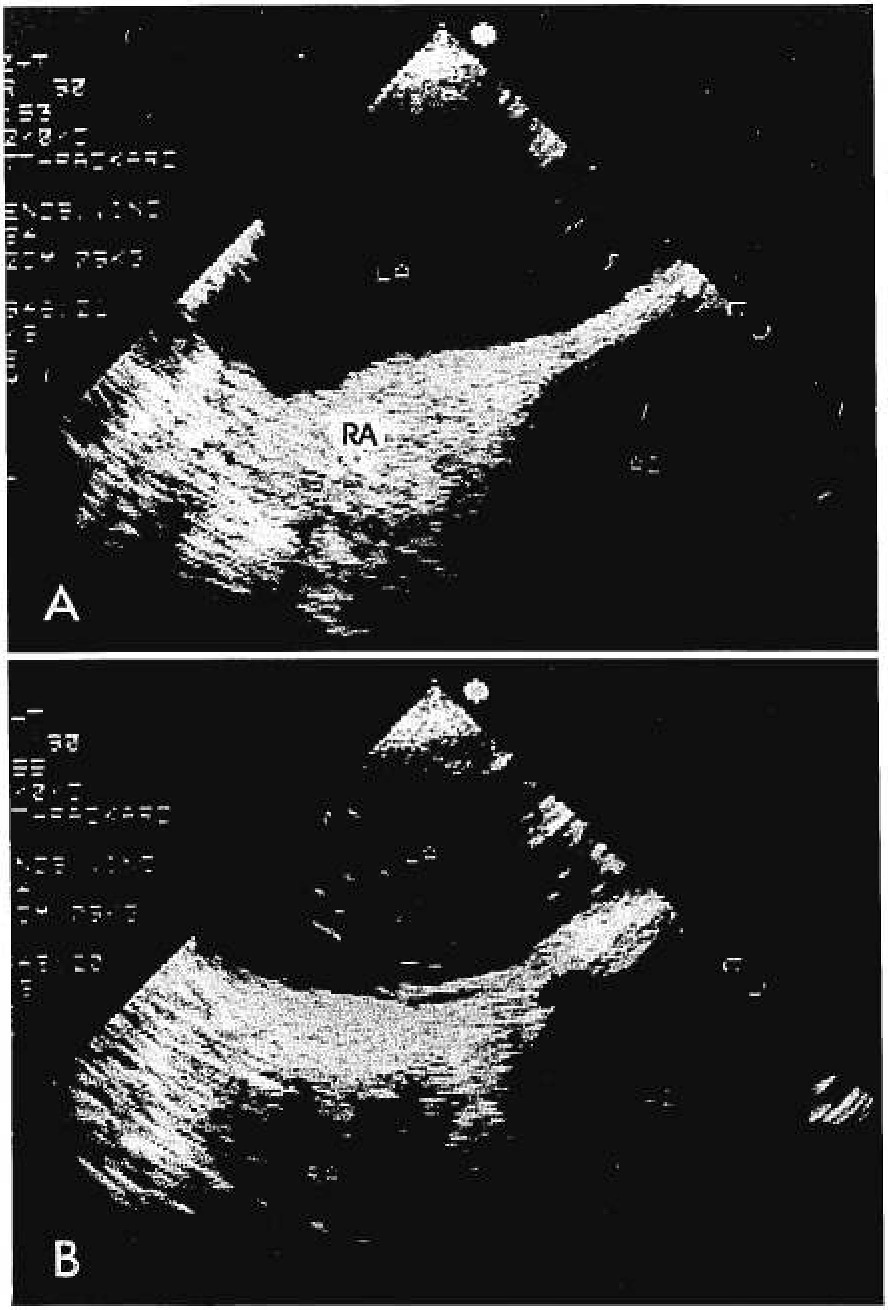

FIG. 2. (*A*) Biatrial echocardiographic view during contrast injection. Note complete opacification of the right atrium. (*B*) Same view as (*A*) after airway pressure release. Note the appearance of echo contrast in the left atrium. RA = right atrium; LA = left atrium; AO = aorta.

Discussion

RELATIONSHIP OF THE CURRENT STUDY TO THE LITERATURE

The presence of PFO is not uncommon. Autopsy studies indicate that the prevalence in the general population ranges between 25 and 35%.[1,8] Although probe patency of the foramen ovale does not guarantee the presence of interatrial shunting, a sensitive diagnostic technique should detect interatrial shunting in a percentage of patients consistent with the prevalence of PFO at autopsy. Studies in otherwise healthy awake patients using contrast echocardiography and Valsalva's maneuver to detect right-to-left shunting at the atrial level had detection rates of 6–18%.[3,4,9,10] Using similar techniques in patients with PFO confirmed by cardiac catheterization and with normal right heart hemodynamics, contrast echocardiography detected only 64% of the defects.[11] In these series of patients without suspected atrial or right heart pathology, the detection rate is significantly lower than would be expected from the autopsy prevalence of PFO.

TABLE 1. Data from Patients with Interatrial Shunting

Patient	Procedure	Contrast-A	Contrast-PP	PWD	CFM	PAP (mmHg)
1	CABG	+	+	—	—	21
2	CABG	+	+	—	—	16
3	AAA	−	+	—	—	23
4	CABG	+	+	R → L	R → L	12
5	CABG/MVR	+	+	R → L	R → L	25
6	CABG	−	−	R → L	R → L	10
7	CABG	−	+	—	—	33
8	CABG	−	+	—	—	17
9	WPW	−	+	—	—	15
10	CABG	−	+	—	—	13
11	CABG	−	−	L → R	L → R	18
12	CABG	−	+	—	—	13
13	CABG	+	+	—	—	15

Contrast-A = contrast evidence of interatrial shunting during apnea; Contrast-PP = contrast evidence of interatrial shunting following positive airway pressure release; PWD = pulsed-wave Doppler evidence of interatrial shunting (flow direction is designated R = right; L = left); CFM = color flow mapping evidence of interatrial shunting (flow direction is designated); PAP = mean pulmonary artery pressure at end-expiration during apnea; CABG = coronary artery bypass grafting; WPW = Wolf-Parkinson-White accessory pathway ablation; MVR = mitral valve replacement; AAA = abdominal aortic aneurysm resection.

In the current study, the prevalence of PFO was found to be 26%. This number approximates the prevalence detected at autopsy and surpasses the detection rate reported previously in both awake and anesthetized patients.

KEY DIFFERENCES IN THE CURRENT STUDY

Although the higher detection rates reported in this study may be due simply to differences in patient populations, there are several key differences in the techniques of this study compared with those of the prior studies. First, most of the other studies imaged the heart with a four-chamber long-axis view, whereas the current study used a biatrial view.[7] The biatrial view limits the sector primarily to the atria, allows the interatrial septum to be visualized in its narrowest dimension, and provides the optimal angle for pulsed-wave and color Doppler interrogation of the FO. Second, the method of saline agitation used in the current study is more vigorous and usually provides better echocardiographic contrast than that provided by simple shaking of the syringe. Third, our technique required that the contrast completely opacified the right atrium. This requirement prevented selective streaming of the contrast away from the region of interest (the FO). Fourth, this study used Doppler techniques to supplement contrast echocardiography and detected two additional patients with interatrial shunting. Contrast injection into the right atrium is most suited for detecting positive contrast from the right to the left atrium. Doppler techniques are particularly helpful for the diagnosis of left-to-right shunting.

Finally, another important aspect of the technique emerged during the course of the study. In one patient there was no shunting during apnea or after release of 20 cmH_2O positive airway pressure. The hemodynamic tracing was examined, and it was noted that at no point did the right atrial pressure exceed the pulmonary capillary wedge pressure. Contrast injection was repeated after the release of 30 cmH_2O positive airway pressure, a step that resulted in the transient elevation of right atrial pressure over pulmonary capillary wedge pressure. Right-to-left contrast shunting also was noted. Therefore, confidence in contrast studies requires documentation that the release of positive airway pressure creates a pressure reversal between the right and left atria. Documentation is best achieved by the use of concomitant hemodynamic recording of the right atrial and pulmonary capillary wedge pressures. However, in some patients this may not be feasible, and observation of the atrial septal motion after airway pressure release may serve as a replacement for invasive hemodynamic monitoring.[12]

LIMITATIONS AND QUESTIONS

The major limitation in this study was the absence of anatomic correlation in 41 of 50 patients. The study could have been performed exclusively in patients undergoing open atrial procedures, but thereby would have selected out specific disease processes. To compare the results to the autopsy and previous studies, it was best to examine the broadest patient population. Despite these attempts, all of the patients did have cardiovascular disease and therefore do not represent a pure population cross section.

One problem related to the use of positive airway pressure is that some patients, such as those who are hypovolemic, may not tolerate the hemodynamic consequences. Airway pressure application may also be a problem in patients with elevated intracranial pressure.

An important question raised in this study is the low detection rate by Doppler techniques and the apparent inconsistency between the contrast and Doppler studies in two patients. Doppler techniques detect abnormal flow velocities due to shunting. In general, the pressure differential between the atria is small, and the resulting

Doppler shift is small and difficult to detect. By comparison, saline contrast echocardiography demonstrates passage of the microbubbles across the interatrial septum, and the detection of these microbubbles does not depend on their velocity but instead on the volume of shunt flow. Thus, the two techniques are complementary. One of the patients had left-to-right shunting on color flow mapping; retrospective inspection of the hemodynamic tracings revealed that because of mitral regurgitation, the respiratory maneuvers did not increase the right atrial pressure over pulmonary capillary wedge pressure. In this setting, Doppler techniques may be superior to contrast echocardiography. In another patient, pressure reversal did occur, and there was Doppler evidence of a PFO, but contrast echocardiography did not demonstrate interatrial shunt flow. Although it is possible that the color diagnosis is incorrect, we have no explanation for the positive Doppler findings. It is possible that although the velocity of the shunt flow was adequate for detection, the volume of shunt flow was not.

Implications and Conclusions

Paradoxical air embolism is a rare complication and may be devastating.[2,13] One means suggested to decrease the risk for paradoxical air embolism is to identify perioperatively those patients at risk for paradoxical air embolism, should venous air embolism occur intraoperatively.[10,14]

Because of the cost, low detection rate, and occurrence of false-negative results, previous investigators have not advocated the use of echocardiography for routine screening of patients at risk for intraoperative emboli.[4-6] In light of the high detection rate reported in the current study, this technique deserves further prospective evaluation. Our results were obtained intraoperatively, when nearly complete physiologic control and monitoring is possible. To justify routine preoperative screening, it is necessary to document that equally high detection rates are possible with similar techniques in awake patients, and it also must be shown that identification of patients at "risk" results in a reduction in morbidity and mortality. Under no circumstances should the use of echocardiography to detect PFO replace the current standard monitors for venous air embolism or decrease the vigilance with which we monitor for venous air embolism.

Another application of the technique presented in this study is the use of contrast and Doppler echocardiography during cardiac surgery to identify patients in whom closure of the defect could easily be accomplished during the primary surgical procedure. In cases in which the cardiac chambers are already open (such as valvular repairs or replacements, ventricular aneurysm resection, and ablation of aberrant pathways), there would be little or no risk added with the procedure. During coronary revascularization, closure of the defect may present an additional risk. In patients with a history of unexplained transient ischemic attacks for which paradoxical emboli may be the cause, this risk may be justified. Further work is needed to determine the risk:benefit ratio in asymptomatic patients.

In conclusion, using simple respiratory maneuvers, a modified contrast echocardiographic technique, and Doppler echocardiographic modalities, intraoperatively we have detected interatrial shunting in 26% of the patients studied. This number exceeds previously reported detection rates and approximates autopsy prevalence rates for PFO. In the circumstances outlined above this technique may prove valuable to patient care.

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