Transesophageal Echocardiographic Guidance of Transcatheter Ventricular Septal Defect Closure

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Objectives. This report describes transesophageal echocardiographic guidance of transcatheter closure of ventricular septal defects and its value as an adjunct to fluoroscopy and angiography in this procedure.

Background. Experience with transcatheter closure of ventricular septal defects has identified a diverse group of patients in whom it may be the procedure of choice. Although facilitating other interventional procedures, such as transcatheter closure of atrial septal defects, the value of transesophageal echocardiographic guidance for transcatheter ventricular septal defect closure has not been documented.

Methods. All patients who underwent ventricular septal defect closure with transesophageal echocardiographic guidance before November 1992 were included. Angiograms and echocardiograms were reviewed to evaluate device position and relation to valve tissue during placement and to assess residual flow after device implantation. The ability of transesophageal echocardiography to assess these variables was compared with fluoroscopy and angiography.

Results. Transesophageal echocardiographic guidance was used in 31 of the 83 catheterizations involving transcatheter ventricular septal defect closure performed between February 1990 and November 1992. Under transesophageal echocardiographic guidance, 45 devices were implanted: 23 in muscular ventricular septal defects, 17 in residual postoperative patch margin defects and 5 in other ventricular septal defects. Transesophageal echocardiographic guidance enhanced assessment of device position and proximity to valve structures and markedly improved assessment of residual flow. Assessment of residual flow with transesophageal echocardiography eliminated the need for multiple angiograms in some patients. Combining transesophageal echocardiography with fluoroscopy and angiography provided the most information.

Conclusions. Transesophageal echocardiography facilitates transcatheter closure of ventricular septal defects by improving assessment of device position and effectiveness of closure. It is indicated when device placement is likely to be difficult or may interfere with valve structures or when multiple interventional procedures are anticipated.

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Several investigators have reported the use of transesophageal echocardiography during interventional catheterization procedures (1-7). Transesophageal echocardiography does not interfere with execution of the procedure and generally provides superior image quality. In this report, we describe the use of transesophageal echocardiographic guidance of transcatheter device occlusion of ventricular septal defects. Possible indications for the use of transesophageal echocardiography during the procedure, the contributions of transesophageal echocardiography to correct device positioning and assessment of results are discussed.

Methods

The medical records, angiograms and echocardiograms of all patients who underwent transcatheter ventricular septal defect closure between February 1, 1990 and November 1, 1992 and who had a transesophageal echocardiogram during the procedure were reviewed. Patients were identified by a search of the computerized data bases for echocardiography and closure devices. Before February, 1990, transesophage-
al echocardiography was not used during transcatheter ventricular septal defect closure.

Informed consent. The Bard Clamshell Septal Occluder used for ventricular septal defect closure is investigational, and its use is currently restricted to centers designated by the Food and Drug Administration. The device placement protocol has been approved by the Food and Drug Administration and by the Committee on Clinical Investigation at Children's Hospital. Informed consent was obtained before all device placements.

Echocardiographic examination. All patients who were candidates for transcatheter ventricular septal defect closure underwent conventional echocardiographic examination before catheterization. Transesophageal echocardiography was used during ventricular septal defect closure in patients who were in one or more of several higher risk categories: 1) multiple ventricular septal defects requiring device closure; 2) anticipation of multiple additional interventional procedures and angiograms during the same catheterization (high contrast load); 3) complex septal anatomy (such as malalignment of the apical septum); and 4) ventricular septal defect in close proximity to valve structures.

Transesophageal echocardiography was performed by one of four faculty echocardiographers, using a Hewlett-Packard Sonos 1000 or 1500 or an Acuson 128 phased-array imaging system equipped with pulsed, continuous wave and color Doppler and a single-plane or biplane transesophageal echocardiographic transducer. A pediatric transducer was used in patients weighing <10 to 12 kg. All patients underwent general anesthesia and intubation before transesophageal echocardiography, to prevent patient movement during ventricular septal defect device deployment.

Methodology for transesophageal echocardiographic guidance of transcatheter ventricular septal defect closure has been described elsewhere (1). Ventricular septal defect anatomy, size, relation of multiple defects, if present, and proximity to valves and other cardiac structures were determined before device placement. Occluder arm position was monitored during device delivery and after release, and effectiveness of closure was evaluated using Doppler color flow mapping.

Cardiac catheterization and ventricular septal defect closure. Baseline hemodynamic variables were measured before ventricular septal defect closure. Candidacy for transcatheter closure and the details of the procedure have been described elsewhere (8,9). Devices used for ventricular septal defect occlusion included the Bard Clamshell Septal Umbrella (17, 23, 28, 33 or 40 mm in diameter) and the Bard FDA Umbrella (12 or 17 mm in diameter). Device position was assessed by fluoroscopy throughout the procedure and afterward by angiography, when possible. The techniques for other interventional procedures performed in some of the patients have been described elsewhere (10-12).

Results

Patient characteristics. Between February 1990 and November 1992, a total of 83 catheterizations involving transcatheter ventricular septal defect closure were performed. Thirty-one of these catheterizations (37%) were done using transesophageal echocardiographic guidance; the clinical characteristics of 29 patients undergoing these 31 catheterizations are described in Table 1 (median age 7.2 years, range 12 months to 80 years; median weight 19.5 kg, range 6.3 to 75).

Ventricular septal defect was the primary cardiac diagnosis in 7 of 29 patients. The other 22 patients included 9 with double-outlet right ventricle or transposition of the great arteries with ventricular septal defect status post Rastelli repair (8) or arterial switch and ventricular septal defect closure (11); 5 with repaired tetralogy of Fallot or tetralogy of Fallot with pulmonary atresia; 5 with an unrepair ed conotruncal malformation with multiple ventricular septal defects; 1 with double-outlet right ventricle with inverted atri a status post Senning and Rastelli; and 2 with a postinfarction ventricular septal defect.

These 29 patients underwent placement of 45 ventricular septal defect devices (43 clamsheII s, 2 patent ductus arteriosus umbrellas) in 23 muscular ventricular septal defects, 17 patch ma in defects, 2 left ventricular to right atrial shunts, 2 postinfarction defects and 1 fenestration in a ventricular septal defect patch.

More than one interventional procedure was performed during 19 (67%) of the 31 cardiac catheterizations (Table 2). Additional procedures included device closure of an atrial septal defect or of one or more additional ventricular septal defects, balloon dilation of pulmonary arteries or of the right or left ventricular outflow tract, stent placement and coil embolization of aortopulmonary collateral vessels.

Fluoroscopic and angiographic evaluation. Device position. After device release, the relation between the device arms and the ventricular septum could be accurately determined by fluoroscopy and angiography in 35 of 45 devices. Of these, 32 devices appeared to be correctly positioned, whereas in the other 3 one or two arms appeared to be on the wrong side of the septum. The relation of the device arms to the septum could not be determined with certainty in the remaining 10 devices.

Relation to valves. Device arms were thought to be within 5 mm of aortic leaflets in seven devices and tricuspid valve apparatus in five. The relation of device arms to valve structures could not be determined by fluoroscopy and angiography in four patients.

Residual flow. Angiography, performed after release of 37 devices, was helpful in assessing ventricular septal defect closure in only 11 (30%), with residual flow graded as trivial in 4, small in 3 and moderate in 4. Angiography was not performed after placement of seven devices because of contrast load limitations and after another because of device embolization.
In summary, fluoroscopy and angiography were inadequate for assessment of device position in 22% and for proximity to valve tissue in 9% of the ventricular septal defect devices placed. The amount of residual flow could not be assessed in 70% of the devices evaluated by angiography.

Transesophageal echocardiographic evaluation. **Device position.** The relation of device arms to the ventricular septum was demonstrated by transesophageal echocardiography in 40 of the 45 devices, although in 2 cases one or two arms were not well imaged. Because of extreme anterior location or acoustic shadowing by patch material, five devices were difficult to image.

**Relation to valves.** Of the 45 devices, 12 were considered close to valve tissue (6 aortic, 6 tricuspid), including 2 cases where the device relation to valve structures could not be assessed by fluoroscopy or angiography. The remaining devices, including those indistinctly imaged, were thought to be distant from the valves. Two devices were considered by angiography to be close to valve structures but were seen as remote by transesophageal echocardiography; review of angiograms and echocardiograms in these two cases revealed that in one the distance to the aortic valve was difficult to determine with certainty by transesophageal echocardiography (and was close by angiography); in the other, review of the angiogram concurred with transesophageal echocardiography that the device was not within 5 mm of the aortic valve.

**Residual flow.** Residual shunting through the ventricular septal defect as assessed by color flow mapping after device placement was absent in five cases, trivial in six, small in eight, moderate in two and large in three. In 11 other defects the amount of flow was significantly reduced but could not
be graded accurately. The amount of residual flow after device placement could not be determined by transesophageal echocardiography in the remaining nine cases.

In summary, transesophageal echocardiography was inadequate for assessment of device arm position in 11% and for residual flow in 20% of devices placed. Proximity to valve tissue could be assessed in 98% of devices.

Additional information obtained by transesophageal echocardiography. Previously unrecognized cardiac abnormalities were discovered in several patients. Large residual interatrial communications were found in two patients who had undergone reparative surgery (one with juxtaposition of the atrial appendages, one with a Senning procedure for inverted atria). These defects had not been detected by routine hemodynamic evaluation before transesophageal echocardiography. In five other postoperative patients (all >5 years old), a patent foramen ovale or small atrial septal defect with detectable flow was identified. Malalignment of the muscular septum apical to the ventricular septal defect was diagnosed in three patients. Two large atrial thrombi were detected in a patient with a postinfarction ventricular septal defect.

Resource utilization. The average duration of transesophageal echocardiographic imaging during transcatheter ventricular septal defect closure in these 31 catheterizations was 2.15 h (range 0.55 to 5.23). No morbidity related to transesophageal echocardiography was observed.

Combined assessment by catheterization and transesophageal echocardiography. Of the five devices poorly imaged by transesophageal echocardiography, three were well imaged by fluoroscopy and angiography, but two were difficult to localize using either modality. In the 26 device closures where angiographic assessment of residual flow was inconclusive, the amount of residual flow could be evaluated by transesophageal echocardiography in 20 (77%). The combination of techniques resulted in improved ability to assess device position, proximity to valves and residual flow (Fig. 1).

Discussion
Use of transesophageal echocardiography to guide several types of interventional procedures has been previously described, including mitral valvuloplasty (2,3), atrial septal defect device placement (4), balloon atrial septostomy (5), endomyocardial biopsy in infants (6) and radiofrequency ablation of bypass tracts (7). We have previously described our early experience with transesophageal echocardiographic guidance of transcatheter closure of several intracardiac defects (1).

Device position. During transcatheter closure of ventricular septal defects, deployment of device arms is guided radiographically using landmarks, such as sternal wires and ribs, because septal and valve structures cannot be visualized fluoroscopically unless extensively calcified (Fig. 2). After delivery of the distal set of arms, tension on the device causes the arms to move in predictable directions if they are properly positioned. However, device arms caught on other cardiac structures (such as valve tissue) may mimic properly positioned arms. In addition, manipulation of the device to assess position can cause arm dislodgment. Interference with valve structures may not be apparent until the device is released, and angiography performed.
TRANSESOPHAGEAL ECHO FOR CATHETER VSD CLOSURE

Figure 2. Fluoroscopic image (long-axial oblique projection) of the ventricular septum with two clamshell devices in place after deployment. Three catheters are present: retrograde in left ventricle, inferior vena cava to pulmonary artery and inferior vena cava across atrial septum to left ventricle). The position of individual device arms with respect to the septum and valve structures is difficult to determine.

Transesophageal echocardiography during device deployment allows continuous visualization of device arms and their proximity to the septum and other cardiac structures in the great majority of patients (Fig. 1 and 3). Arms that are positioned improperly or that interfere with valve function can be identified before the proximal portion of the device is deployed, while retraction and redelivery are still possible. Incorrect arm position appears less likely if transesophageal echocardiographic guidance is used.

Figure 3. Four-chamber transesophageal echocardiographic image of a clamshell device properly positioned in a midmuscular ventricular septal defect. LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle.

Although some defects (particularly very anterior ones) can be difficult to image with transesophageal echocardiography, the combination of transesophageal echocardiography and fluoroscopy is likely to provide the most accurate assessment of device position.

Residual flow. The angiographic assessment of residual flow is affected by the amount of contrast medium used, proximity of the injection to the defect and the time elapsed since device placement. Transesophageal echocardiography may provide a more physiologic assessment of residual flow and can be performed at multiple intervals after device placement.

In 20 ventricular septal defect devices with inconclusive angiograms, transesophageal echocardiography provided enough information about the amount and location of residual flow that further angiography was not necessary. Use of transesophageal echocardiography in such situations reduces contrast load and radiation, increasing the number of diagnostic and interventional procedures that can be performed during a single catheterization. Further catheterizations, in turn, may be avoided.

At our institution, transcatheter device closure is used increasingly for management of selected unoperated ventricular septal defects (9). Transcatheter closure of residual postoperative defects has also proved useful as an alternative to reoperation, particularly for poor operative candidates (13). Although experience with transcatheter closure of postinfarction ventricular septal defects is limited (8, 14), further experience may identify patients in whom transcatheter closure improves survival.

Figure 4. Angiogram after placement of the device shown in Figure 3. The location of the residual flow across the septum (i.e., through the same defect or a separate defect at the same level) is difficult to determine by angiography alone.
Indications for transesophageal echocardiography. On review of the 83 catheterizations involving ventricular septal defect device placement performed during the study period, transesophageal echocardiographic guidance appears to be indicated when 1) the ventricular septal defect is near semilunar or atriocentrical valve tissue; 2) the defect is very large or complex, or septal anatomy is unusual (as with malalignment of the apical portion of the septum); 3) the location or number of ventricular septal defects is still in question after conventional echocardiography and angiography; or 4) the need for multiple interventional procedures during the same catheterization is anticipated (Fig. 4 and 5). Other indications for transesophageal echocardiographic guidance of the procedure might include renal failure or allergy to contrast material.

Advantages of transesophageal echocardiography over conventional echocardiography. The superior imaging capability of transesophageal echocardiography compared with surface echo has been well described. Transesophageal echocardiography may identify previously unrecognized but important cardiac abnormalities, as our study population revealed. More important for transcatheter closure of cardiac defects, however, is the ability to continuously monitor device position and relation to valve tissue during device delivery without interrupting or interfering with fluoroscopy or catheter manipulation (1,2).

Study limitations. Very anterior ventricular septal defect and some aortic defects can be difficult to image by transesophageal echocardiography. Technologic advances may improve far-field penetration and resolution. Conventional echocardiography, although it may provide superior images of these areas, is likely to interfere with the closure procedure and has not been useful. General anesthesia is necessary to prevent patient movement during transcatheter ventricular septal defect closure, particularly if transesophageal echocardiography is used.

Resource utilization. Transesophageal echocardiographic guidance of transcatheter ventricular septal defect closure requires a time commitment by the echocardiographer and equipment that may be prohibitive in some situations.

Conclusions. Transesophageal echocardiography is a useful and frequently necessary adjunct to fluoroscopy and angiography for guidance of transcatheter ventricular septal defect closure and is especially indicated when positioning of the device is likely to be difficult or to interfere with valve structures or when multiple interventional procedures are anticipated.

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References