Utility of Three-Dimensional Echocardiography During Balloon Mitral Valvuloplasty

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Objectives. We investigated the role of three-dimensional echocardiography in assessing mitral valve anatomy in greater detail in patients immediately before and after balloon mitral valvuloplasty (BMV).

Background. Three-dimensional echocardiography is a recently developed, evolving imaging technique that allows visualization of intracardiac structures from any perspective.

Methods. We studied 19 patients undergoing BMV using transesophageal echocardiography (TEE) (Chicago, Illinois) to image the mitral valve. The TEE was interfaced to a TomTec threedimensional workstation that allows electrocardiographic and respiratory cycle gated image acquisition. The acquired images are digitized, and after postprocessing a three-dimensional image is reconstructed. The mitral valve was viewed “en-face” as if looking up from the left ventricle.

Results. The mean mitral valve area (by pressure half-time from the Doppler of the two-dimensional echocardiogram) increased after BMV from $0.86 \pm 0.06 \text{ cm}^2$ to $2.07 \pm 0.10 \text{ cm}^2$, $p < 0.0001$. This was similar to the mitral valve areas obtained by planimetry from the three-dimensional images. The three-dimensional reconstructions showed a complete commissural split in 10 patients and partial splitting in 9 patients. In three of the eight patients who had an increase in the amount of mitral regurgitation secondary to BMV, the three-dimensional reconstructions were able to detect tears within the valve leaflet. One leaflet tear actually extended up to the mitral valve annulus and was associated with the only case of severe mitral regurgitation.

Conclusions. The three-dimensional echocardiographic reconstruction enabled visualization of the mitral valve so that commissural splitting and leaflet tears not seen on the two-dimensional echocardiogram became visible.

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Percutaneous balloon mitral valvuloplasty (BMV) is an alternative to mitral valve surgery in a selected group of patients (1). Transthoracic echocardiography is routinely used to screen patients who are thought to be appropriate candidates for this procedure (2,3). Transesophageal echocardiography (TEE) has been shown to be an invaluable, safe imaging tool to further screen patients, as well as to assist with the procedure and monitor its complications (4,5).

Three-dimensional echocardiography is a recently developed imaging technique. By using a multiplane probe, ultrasound images are obtained by sequential rotational acquisitions that are gated to the respiratory cycle and heart rate. This gives a volume-rendered three-dimensional image of the heart that allows one to view intracardiac structures from any perspective (6–8). This technique has been used to examine congenital cardiac abnormalities such as atrial septal defects (9), diseases of the thoracic aorta (10) and mitral valve disease (11), all in much greater detail than with standard two-dimensional echocardiography.

We therefore sought to evaluate the usefulness of this three-dimensional imaging technique to examine in greater detail the effects of balloon valvuloplasty on the mitral valve.

Methods

Patients/BMV. This study included patients who were undergoing BMV for rheumatic mitral stenosis at New York University Medical Center or the Escorts Heart Institute in whom a TEE was requested to assist in the procedure. All patients provided written informed consent. Conscious sedation using intravenous midazolam or morphine sulfate was used as needed. Right and left heart catheterization was performed. All patients underwent BMV with an Inoue balloon (Torey Medical Group, Houston, Texas).

Two-dimensional TEE examination. A 5-MHz multiplane transesophageal transducer was connected to a Hewlett-Packard Sonos 1500 or 2500 system (Andover, Massachusetts). After the femoral arterial and venous sheaths were placed, the esophagus was intubated with the TEE probe, which remained in the esophagus until the procedure was completed. Before
balloon inflations, a full TEE examination was performed with emphasis on the mitral valve anatomy (as well as the mitral valve area and amount of regurgitation). Evidence of thrombi in the left atrium or left atrial appendage was also sought. During the transseptal puncture, TEE assisted in selecting the site for the puncture and in the proper placement of the Brockenbrough needle by visualizing its indentation of the interatrial septum. Transesophageal echocardiography was also able to help guide the balloon catheter into proper position within the mitral valve orifice. Between balloon inflations TEE was used to assess the mitral valve area and amount of mitral regurgitation. Finally, when BMV was completed, another full TEE examination was performed to assess the mitral valve anatomy, valve area and degree of insufficiency, as well as the occurrence and size of a newly created atrial septal defect.

**Three-dimensional TEE examination.** During the initial and final TEE examinations ultrasound data were acquired for dynamic three-dimensional reconstruction. This was accomplished by interfacing the Hewlett-Packard Sonos system with a system capable of three-dimensional echocardiographic reconstruction (TomTec Echo-Scan; Chicago, Illinois). Rotational scanning was used. The TomTec computer obtained ultrasonographic images while the TEE transducer was rotated every 30 minutes around a 180° arc. Image acquisition was gated to the electrocardiogram and to the respiratory cycle (as determined by chest wall impedance). Therefore, 60 images were obtained for each cardiac cycle. The raw ultrasonographic data were digitized, stored and then processed offline using the TomTec system. Two data sets were collected for each prevalvuloplasty and postvalvuloplasty study.

**Image display and analysis.** The digitized data were reformatted and interpolated into a cubic data set by filling in the gaps between pixels to create individual volume elements or voxels. This cubic data set could then be rotated in any direction, allowing unlimited cut planes irrespective of the original ultrasonographic window. Once a cut plane was chosen, a volume-rendered three-dimensional image was produced by a combination of distance, gradient and texture shading (6). For our study a short-axis view of the left ventricle at the level of the papillary muscle was used to view the mitral valve (as if looking up from the left ventricle into the valve). The mitral valve leaflets, annulus and commissures were identified, inspected and compared in both the prevalvuloplasty and postvalvuloplasty studies. The mitral valve area was also measured by planimetry in this view. Several tomographic images of the valve orifice during diastole were inspected, and the image with the smallest mitral valve orifice was used. This was compared with the mitral valve area calculated by the pressure half-time method (12) from the continuous-wave Doppler tracing of the mitral inflow velocity obtained from the two-dimensional TEE. The degree of mitral regurgitation was estimated from the color Doppler signal, also obtained from the two-dimensional TEE.

**Statistical analysis.** The mitral valve areas were reported as the mean ± SE. The prevalvuloplasty and postvalvuloplasty valve areas were compared using a two-tailed t test. A p value ≤0.05 was considered statistically significant.

**Results**

**Patients.** There were 19 patients (12 females) studied at both institutions who had three-dimensional echocardiograms performed just before and immediately after BMV. They had a mean age of 34 years (range 12 to 55 years), and all patients had rheumatic mitral stenosis as determined by history, physical examination and echocardiography. Fourteen patients were in normal sinus rhythm, and atrial fibrillation was present in five patients. All of the patients underwent BMV using an Inoue balloon, as previously described (13,14).

**Two-dimensional TEE.** There was improvement in the mitral valve area in 18 of the 19 patients. The mitral valve area increased from a mean of 0.86 ± 0.06 cm² before BMV to 2.07 ± 0.10 cm² (p < 0.0001) immediately after valvuloplasty. Eight of the 19 patients had worsening of their mitral regurgitation immediately after valvuloplasty (Fig. 1). Before BMV seven patients had no evidence of mitral regurgitation on color Doppler, eight patients had mild regurgitation and four patients had moderate regurgitation. After BMV 1 patient had no detectable mitral regurgitation by color Doppler, 14 patients had mild regurgitation, 3 patients had moderate regurgitation and 1 patient had severe regurgitation. There were no complications from either the TEE or sedation.

**Three-dimensional TEE.** All 19 patients had three-dimensional TEE reconstructions of their mitral valve both before and after BMV. The quality of the three-dimensional reconstruction was considered excellent in 11 patients (58%), good in 6 patients (32%) and fair to poor in 2 patients (10%). The approximate time needed to obtain the ultrasonographic images for the three-dimensional study was 3 to 8 min (those patients in atrial fibrillation had a longer acquisition time). The time needed to postprocess and reconstruct a three-dimensional image ranged from 10 to 30 min.

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**Abbreviations and Acronyms**

BMV = balloon mitral valvuloplasty

TEE = transesophageal echocardiography
Three-dimensional TEE was then used to evaluate the anatomy of the mitral valve and to help elucidate the mechanism by which BMV increased the mitral valve area. We found that actual splitting of the commissures occurred in all of our patients (Fig. 2). This was identified on the postvalvuloplasty three-dimensional reconstruction as a new area of echo dropout along the long axis of the mitral valve orifice which was contiguous with the orifice. Ten of the patients had a complete commissural split which was defined as splitting of the fused mitral commissures on both sides of the valve orifice up to the level of the mitral valve annulus. The remaining nine patients had a partial commissural split which was defined as splitting of the commissures either on one side or for only several millimeters from the valve orifice. When comparing the increase in mitral valve area between these two groups, the group that had complete commissural splitting had a 63% larger increase in valve area after balloon valvuloplasty as compared with the group with partial commissural splitting (Fig. 3).

In 17 patients both prevalvuloplasty and postvalvuloplasty mitral valve areas were measured from the three-dimensional reconstruction by planimetry of the mitral valve orifice in diastole. Before balloon valvuloplasty the mean mitral valve area was $0.81 \pm 0.06 \text{ cm}^2$, and after valvuloplasty the mean mitral valve area was $2.06 \pm 0.08 \text{ cm}^2$. These results were similar to the mitral valve areas calculated by pressure half-time.

Of the eight patients who developed an increase in mitral regurgitation, examination of the three-dimensional TEE revealed a tear in the leaflet of the mitral valve in three patients (38%). This was identified as an area of ultrasound drop-out perpendicular to or off the long axis of the mitral valve orifice (Fig. 4). Two of the tears were mild, involving only several millimeters of the leaflet (one patient who had no mitral regurgitation initially developed mild regurgitation; the other patient had mild mitral regurgitation that became moderate). One tear was more extensive, appearing to involve the entire leaflet (this patient initially had moderate mitral regurgitation, which then became severe).

**Figure 2.** Diastolic frames of the three-dimensional reconstruction of the mitral valve orifice (○) as seen from the left ventricle. The mitral valve area increased from 1.0 cm$^2$ before BMV to 2.0 cm$^2$ after BMV. The site of the commissural split is clearly demonstrated (arrow).

**Figure 3.** The change in mitral valve area (centimeters squared), as measured by pressure half-time, resulting from BMV in patients with a complete versus a partial commissural split.

**Figure 4.** Diastolic frames of the three-dimensional reconstruction of the mitral valve orifice as seen from the left ventricle. A leaflet tear is noted in the post-BMV image (arrow). The tear is perpendicular to the long axis of the mitral valve orifice.
Discussion

Percutaneous BMV is a safe, effective, less invasive alternative to surgery for selected patients with mitral stenosis (1,14). It has been shown to convey a similar improvement in hemodynamics, valve area and symptoms for up to 2 years after the procedure as compared with open surgical commissurotomy (1). It is, however, not without morbidity, the most serious being cardiac perforation, systemic emboli and the development of mitral regurgitation (15). These potentially lethal complications can be minimized with the use of echocardiography.

Doppler echocardiography has a clear and well-established role in evaluating patients with mitral stenosis who undergo BMV. Transthoracic echocardiography is a standard screening tool that is used to assess the mitral valve and submitral apparatus in patients who are potential candidates for this procedure (2,3,16). It has also been used to monitor patients during BMV (17).

Transesophageal echocardiography is a safe and valuable imaging technique that is being used more frequently in association with BMV (4). Immediately before BMV, TEE can be used to clearly visualize the left atrium, left atrial appendage and interatrial septum for the presence of thrombi, which are a potential source for systemic embolization during the procedure (3,5). During valvuloplasty TEE has been shown to be an invaluable aid in guiding the transseptal puncture by visualizing the “Tenting” of the interatrial septum by the Brockenbrough needle (18). Transesophageal echocardiography is also useful in guiding the balloon catheter across the mitral valve (4,18) and obtaining a quick and accurate assessment of the mitral valve area and the amount of mitral regurgitation (4). After valvuloplasty TEE can assess the adequacy of the procedure (3,4) and identify the presence, exact location and size of iatrogenic atrial septal defects (19).

In this study we have shown the advantages of obtaining three-dimensional echocardiographic reconstructions during BMV. This technique offers the ability to view the mitral valve from any cut-plane of the three-dimensional data set. By viewing the mitral valve from the perspective of looking up from the left ventricle, the mitral leaflets, commissures and mitral annulus were easily visualized en-face. The two-dimensional TEE can accurately visualize a larger mitral valve orifice or an increase in the amount of mitral regurgitation. However, it is often difficult and potentially inaccurate to mentally reconstruct a three-dimensional image from the two-dimensional echocardiographic images. Therefore, by comparing the initial three-dimensional reconstruction to the one obtained after the procedure, the extent of commissural splitting was easily evaluated and was shown to be related to the extent of improvement in mitral valve area with BMV. When the development of worsening of mitral insufficiency complicated BMV, leaflet tears were visualized in 38% of patients. What three-dimensional reconstruction provides that is not obtainable from two-dimensional echocardiography is the mechanism by which valve area increases, as well as the detection of leaflet tears.

The three-dimensional echocardiographic reconstructions correlate well with what is seen on pathologic specimens and direct visual inspection of the valves of patients who underwent BMV. Hogan et al. (20) analyzed pathologic specimens of mitral valves in 11 patients who underwent BMV and found that fracture of the commissural fusion was the fundamental mechanism for the success of the procedure. This was also described by Inoue et al. (13), who were the first to describe the anatomic mechanism of successful BMV in patients undergoing open commissurotomy. Tears of the mitral valve leaflet were shown to be responsible for the development of mitral regurgitation secondary to balloon valvuloplasty in three-fifths of mitral valves studied pathologically (21).

Limitations. There are several possible limitations of three-dimensional volume-rendered echocardiographic reconstructions. This technique is extremely sensitive to proper gain settings from the two-dimensional data acquisition as well as to the level of threshold chosen (which defines the interface between tissue and blood) during the three-dimensional reconstruction. An inappropriate setting of either modality can result in ultrasonographic dropout, which would distort the accurate visualization of the valve anatomy. During data acquisition three-dimensional echocardiographic reconstructions are also very sensitive to both patient and operator movement, either of which can distort the image. Also, the time required for data acquisition and reconstruction, although improving, is still too long for the three-dimensional data to be obtained between balloon inflations.

Measuring the mitral valve area by pressure half-time after BMV can be inaccurate secondary to changes in left atrial and ventricular compliance as well as the creation of an atrial septal defect (22). The three-dimensional reconstruction allows us to measure the mitral valve area by planimetry by choosing the cut-plane with the smallest mitral valve orifice. Although three-dimensional planimetry could be affected by gain settings and postprocessing, we found these results to be similar to the mitral valve area measured by pressure half-time, and we believe that this merits further investigation with a larger number of patients.

Conclusions. Three-dimensional echocardiographic reconstruction of the mitral valve obtained by TEE during BMV is a new, noninvasive imaging technique that can more accurately visualize the mechanisms of successful BMV, as well as some of its complications. This can potentially be used to further guide and optimize the results of BMV by visualizing the extent of commissural splitting so that a maximal mitral valve area can be obtained safely. It may also help prevent the development of significant mitral regurgitation during the procedure. Visualizing a small tear of the mitral valve leaflet associated with only minimal valvular regurgitation may prevent another balloon inflation that may worsen the tear and create more significant mitral regurgitation. Further improvements in the hardware and software of this echocardiographic system are needed to test this hypothesis so that larger studies
can be conducted with three-dimensional image reconstruction performed between balloon inflations.

References


