Intraoperative Doppler Color Flow Mapping for Decision-Making in Valve Repair for Mitral Regurgitation

Technique and Results in 100 Patients

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Mitral valve repair provides substantial advantages over mitral valve replacement in patients with severe mitral regurgitation. However, because of the possibility of persistent regurgitation, an intraoperative technique is needed to provide an immediate and accurate assessment of the adequacy of the repair before closure of the chest. One hundred patients with pure mitral regurgitation were studied with intraoperative epicardial Doppler color flow mapping immediately before and after valve repair. Intraoperative assessment of the severity of mitral regurgitation showed good agreement with preoperative left ventriculography and with standard precordial Doppler echocardiography before and after surgery. Postrepair intraoperative Doppler studies showed satisfactory surgical results in 92 patients. Postrepair intraoperative Doppler studies in the remaining eight patients demonstrated unsatisfactory results: persistent significant regurgitation in four, systolic anterior motion of the mitral valve with dynamic left ventricular outflow tract obstruction in three, and a persistent flail leaflet in one. In six of the eight patients, further surgery was performed during the same thoracotomy. In two patients, the intraoperative postrepair Doppler findings of persistent regurgitation were confirmed on precordial Doppler studies within 5 days, and mitral reoperation was required. Intraoperative epicardial Doppler color flow mapping provided a “safety net” that ensured a successful outcome in all 100 patients by providing the surgeon with a direct means to assess the success of the operation and the need for further surgery. (Circulation 1990;81:556–566)

Mitral valve repair corrects mitral regurgitation with fewer complications than with implantation of a mitral valve prosthesis.1–5 Our use of mitral valve repair on more than 900 patients has also been favorable in comparison to mitral valve replacement in terms of lower operative mortality, preservation of ventricular function, fewer embolic episodes, and improved early survival.4,5 If durability continues to be as good as it has been in our early experience, mitral repair may represent the procedure of choice in many patients with mitral regurgitation. However, valve reconstruction may not be feasible or successful in all patients with mitral regurgitation; in some patients, regurgitation may persist at the end of the operation. Therefore, the results of mitral reconstruction might be further enhanced by a rapid and reliable intraoperative method of detecting and quantitating residual mitral regurgitation.

The purpose of the present study was to determine the usefulness of intraoperative epicardial Doppler color flow mapping in evaluating the integrity of the mitral valve immediately after valve repair for mitral regurgitation.

Methods

Patients

During a 30-month period, 392 mitral operations were performed at our institution in patients with mitral regurgitation without significant concomitant stenosis. Of the 250 patients who had valve repair as the primary surgical treatment during this period, echocardiographic equipment was available in 100 patients to perform intraoperative echocardiography.
before and after cardiopulmonary bypass. No other selection criteria were used regarding the decision to include patients in this series. Therefore, the study was composed of 100 patients who represented all individuals with pure mitral regurgitation who were imaged during the study period with intraoperative Doppler flow mapping before and after valve repair. There were 52 women and 48 men with an age range of 26–82 years (mean age, 61 years).

The etiology of mitral regurgitation included myxomatous prolapse in 57 patients, ischemic heart disease in 24, isolated annular dilatation in 10, rheumatic disease in eight, and a congenital cleft mitral valve in one. Of the 24 patients with ischemic mitral regurgitation, 16 had displacement of the papillary muscles and eight had elongation or rupture of a papillary muscle as the mechanism of dysfunction. In addition, 53 of the 100 patients had ruptured chordae tendineae. All patients had moderately severe (3+) to severe (4+) mitral regurgitation on their preoperative cardiac catheterization, their preoperative transthoracic Doppler examinations in the echocardiographic laboratory, or both. Thirty-nine patients had concomitant coronary or other valvular surgery.

**Transthoracic Angiographic Examinations**

Ninety-eight of the 100 patients underwent preoperative cardiac catheterization including left ventricular angiography. In 95 patients, the severity of mitral regurgitation was assessed on a scale of 0 to 4+ on the basis of criteria previously defined by Sellers et al. The angiograms of three patients were uninterpretable due to induced ventricular arrhythmias or other technical factors.

**Transthoracic Doppler Echocardiographic Examinations**

The transthoracic Doppler studies were performed under standard ambulatory conditions using several commercially available instruments. In many cases, more than one instrument was used for an individual patient to optimize the imaging and Doppler data obtained. The Doppler examinations were performed in the continuous wave, pulsed wave, and color flow mapping modes to determine the presence and severity of the mitral regurgitation by mapping the spatial distribution of the mitral regurgitant jet in the left atrium. Multiple image planes were used for Doppler mapping, including the parasternal long-axis, parasternal short-axis, apical four-chamber, apical two-chamber, and apical long-axis views. The severity of mitral regurgitation was analyzed based on the spatial distribution of the systolic flow disturbance in the left atrium, using published criteria for pulsed and color flow techniques. Transthoracic Doppler echocardiographic examinations were available preoperatively in 90 patients and postoperatively in 83 patients.

**Intraoperative Two-dimensional Doppler Color Flow Imaging**

This research was begun after approval for investigations in human subjects by the Institutional Review Board and Cardiovascular Study Section of The Cleveland Clinic Foundation. Color flow images were recorded with a Corometrics-Aloka model 880 or 860 (Wallingford, Connecticut), a Toshiba SSH-65A (Tustin, California), or a Hewlett-Packard Revision K (Andover, Massachusetts) echocardiographic system with phased-array imaging transducers of 3.5–5.0 MHz. We have previously published descriptions of our techniques for insertion of the transducer into two sterile sleeves (CIVCO Medical Instruments, Kalona, Iowa) and placement of ultrasonic gel inside the sleeve to obliterate the air space between the face of the transducer and the sleeve.

Doppler color flow mapping was used to image each patient’s heart before and after valve repair in the operating room. The prerepair study was performed after median sternotomy but before institution of cardiopulmonary bypass. The intraoperative postrepair study was performed after cardiopulmonary bypass was discontinued and the patient stabilized hemodynamically. Because the severity of mitral regurgitation varies with changes in loading conditions, in equivocal cases after valve repair, and whenever patients were significantly hypotensive or hypovolemic, the blood pressure was raised pharmacologically or with volume expansion before the postpump echocardiographic study to approximate hemodynamics as they would be under ambulatory conditions.

For each intraoperative study, the transducer within the sleeve was placed directly onto the beating heart to record two-dimensional and Doppler color flow images with contact that was sufficient to obtain an optimal acoustic interface but was not heavy enough to induce ventricular arrhythmias or hemodynamic compromise. Minor adjustments in transducer position were often required to record clear images throughout the entire cardiac cycle.

Four transducer positions for intraoperative epicardial echocardiography previously published in video and print form were developed early in our experience. This approach permits a comprehensive evaluation of the degree of mitral regurgitation. It is mandatory for optimal Doppler echocardiographic assessment to use all available views.

For the parasternal-equivalent position, the transducer was placed on the anterior surface of the right ventricular outflow tract with the image plane parallel to the long axis of the left ventricle. In the parasternal long-axis equivalent image (Figure 1), the left atrium was interrogated in an anteroposterior plane extending from the mitral valve in a right and superior direction toward the fundus of the left atrium.

For the aortopulmonary sulcus imaging position, the transducer was placed to the left of the ascending aorta, nestled in the sulcus between the aorta and pulmonary artery. The ultrasound beam was directed posteriorly and inferiorly, rotated 60° clockwise from the parasternal long axis. The aortopulmonary sulcus...
FIGURE 1. Intraoperative imaging using the parasternal equivalent transducer position. Left: Drawing of the transducer on the heart as viewed by the surgeon during midsternal thoracotomy. Right: Long-axis two-dimensional echocardiographic image (as if viewed from the left side of the patient) showing a flail portion of the posterior mitral valve leaflet and an enlarged left atrium (LA). LV, left ventricle.

long-axis plane (Figure 2) subtended the left atrium from the mitral valve in a superior direction, including the left anterior and the right posterior portions of the left atrium.

The subcostal-equivalent imaging position (Figure 3) was obtained by placing the transducer along the diaphragmatic surface of the right ventricle and pointing it in a posterosuperior direction at a 30–60° angle from the frontal plane. The left atrium was interrogated from the mitral valve toward the superior free wall of the left atrium. The more superficial portion of the left atrium interrogated was anteromedial, adjacent to the atrial septum. The portion of the left atrium that was within the image at greater depth was the posterosuperior left atrium.

For the aortasuperior vena cava sulcus position, the transducer was placed against the right side of the aorta, pointing in a posteroinferior and leftward direction toward the left ventricle and the mitral valve. The long-axis image from this position (Figure 4) interrogated the left atrium from the mitral valve to the right and superiorly, with excellent visualiza-

FIGURE 2. Intraoperative imaging using the aortopulmonary sulcus transducer position. Left: Diagram of the transducer on the heart. Right: Long-axis two-dimensional echocardiographic image showing the left atrium (LA) and left ventricle (LV). Note that the aorta (AO) is more steeply angled toward the top of the image compared with Figure 1.
tion of the superior portions of the left atrium both anteriorly and posteriorly.

After making transducer and machine adjustments to optimize the image, we recorded a sequence of two-dimensional echocardiographic images, followed first by Doppler color flow mapping to interrogate intracardiac flow and then by structural imaging to reconfirm the transducer position. During the Doppler color flow imaging, the transducer was swept from side to side to interrogate additional portions of the left atrium and search for the plane in which the maximum amount of regurgitation could be seen.

Short-axis planes were obtained by rotating the transducer 90° from each of these four long-axis positions and were particularly useful from the parasternal and subcostal equivalent planes. The heart was scanned in short axis from the cardiac apex superiorly to the dome of the left atrium. Short-axis scanning with color flow mapping helped to construct a three-dimensional impression of the spatial distri-

**FIGURE 3.** Intraoperative imaging using the subcostal equivalent transducer position in a patient with severe posterior mitral leaflet prolapse (arrow). Left: Diagram of the transducer on the heart. Right: Long-axis (four-chamber) two-dimensional echocardiographic image showing the left atrium (LA) and left ventricle (LV).

**FIGURE 4.** Intraoperative imaging using the aortasuperior vena cava transducer position. Left: Diagram of the transducer on the heart. Right: Long-axis two-dimensional echocardiographic image showing the left atrium (LA) and left ventricle (LV). Note that flow in the aorta (AO) is aligned almost parallel to the ultrasound beam.
bution of the regurgitant jet and to identify the direction of eccentric mitral regurgitant jets. After noting jet location in short axis, the echocardiographer would return the transducer to the long-axis orientation to adjust the plane medially or laterally to find the maximum mitral regurgitant jet. Once we had gained experience with this technique, the total duration of imaging time ranged from 3 to 8 minutes with a mean of about 5 minutes for each before- and after-repair study.

**Adjustment of instrument settings.** The echocardiographer subjectively adjusted the color flow mapping instrument to optimum settings for the individual patient and the individual image plane. In all studies, the lowest (usually 4 KHz) pulse repetition frequency was used. Color gain controls were adjusted to obtain a barely perceptible amount of background color “speckle” in the far field. The sector angle was kept narrow, usually 30–60°, to obtain acceptable frame rates in the range of 8–15 frames per second. Images were recorded on 1/2-in. VHS format videotape for subsequent analysis.

**Real-time assessment of mitral regurgitation in the operating room.** In the first phase of this study, which included the first 33 patients, we developed our methods of real-time visual assessment of the amount of regurgitation, but we did not use the data to make decisions in the operating room. For the remaining 67 patients, we used our real-time visual assessment of the amount of mitral regurgitation according to a 0–4+ scale to make decisions about the adequacy of the repair and the advisability of intervening with further surgery. This assessment was based on our experience with the previous patients and involved a visual average of the spatial distribution of the mitral regurgitation jet from multiple image planes.

**Off-line echocardiographic data analysis.** Echocardiographic images from all 100 patients were evaluated from videotapes in a random sequence, using an off-line system, without knowledge of the clinical status of the patient or the preoperative angiographic or Doppler data. Each long-axis imaging sequence from all four imaging planes described above was scanned to find the sections with stable cardiac rhythm and transducer position that best depicted the anatomy and flow abnormalities. We analyzed the video tapes frame by frame, searching the sequence from each imaging plane for the three still frames with the maximum left atrial jet area of mitral regurgitation, regardless of the timing during systole or sequence in the imaging run. From these images, the area of the mosaic, multicolored, mitral regurgitation jet was measured, the area of the left atrium was measured, and the results of each were averaged. The area of the disturbed flow approximated by the mosaic-colored area in each image plane was expressed as the percentage of the left atrial area subtended by the jet. Because mitral regurgitation jets are often eccentric, the percentage of left atrial area subtended by the jet of a given patient often varied among various image planes. Therefore, all good-quality image planes available were averaged to obtain the mean percentage of the left atrial area subtended by the mitral regurgitation jet. This percentage was then used with the ranges listed below to derive severity of mitral regurgitation on a 0–4+ scale, which was used for comparisons with the estimates made visually in the operating room and for all subsequent analysis.

**Criteria for severity of mitral regurgitation.** The average percentage of the left atrial area subtended by the mitral regurgitation jet was translated to a 0–4+ scale for mitral regurgitation. The criteria used for this translation were 1–15%, 1+; 16–35%, 2+; 36–55%, 3+; and more than 55%, 4+. These criteria were developed during our off-line analysis of the first 33 patients. The criteria subsequently used to report results were available of the intraoperative echocardiographic studies in all 100 patients.

**Interobserver and Intraobserver Variation**

Intraobserver variation analysis for paired observations by observer 1 showed a mean of 2.38±3.20% difference in percentage left atrial area subtended (r=0.987, n=87, y=0.998x−0.004), whereas paired readings by observer 2 showed a mean of 2.73±4.01% difference (r=0.980, n=86, y=0.969x−0.006). Interobserver variation for paired observations of observer 1 compared with observer 2 showed a mean of 6.26±9.0% difference (r=0.915, n=86, y=0.869x−0.0046).

**Results**

**Intraoperative Doppler Data**

Of the 100 patients in this study, 54 had 4+, 28 had 3+, and 18 had 2+ mitral regurgitation on the intraoperative prerepair assessment by Doppler color flow imaging (Figure 5, left column). After valve repair, intraoperative Doppler color flow mapping showed that the mitral regurgitation was eliminated in 80 of 100 patients (Figures 5, middle column, and Figure 6). In 12 patients, the mitral regurgitation after the initial repair was mild (1+). Of the remaining eight patients, the amount of mitral regurgitation detected after repair by intraoperative Doppler studies was 3+ in four patients and 2+ in four patients. In two patients in whom the postrepair intraoperative studies showed 3+ regurgitation early in our series, no change was made in patient management. During the intraoperative postrepair Doppler study in these two patients, the left atrial pressure was less than 12 mm Hg, the cardiac index was in the lower range of normal, and the left atrium revealed no palpable thrill. Postoperatively, both had suboptimal hemodynamic status with low cardiac index and high left atrial pressure, and they could not be weaned from mechanical ventilation. In both patients, standard transthoracic echocardiographic studies in the intensive care unit showed severe mitral regurgitation. Both patients required reoperation, respectively, 2 and 5 days postoperatively.
Six patients underwent further surgery during the same thoracotomy on the basis of the intraoperative echocardiographic and Doppler findings. In each, cardiopulmonary bypass was reestablished, and the left atrium was re-opened through the same atriotomy. In two patients with persistent mitral regurgitation (3+ in one patient and 2+ in the other patient), the mitral repair was revised using further chordal shortening and realignment of the annular support. Repeat intraoperative Doppler color flow imaging after the second repair revealed improvement in the regurgitation, and both patients recovered uneventfully. In one patient, a portion of persistent flail leaflet was noted on the intraoperative postrepair images; despite the absence of any regurgitation by Doppler color flow mapping, cardiopulmonary bypass was reinstituted for resection of the flail segment.

In three patients, the postrepair intraoperative Doppler study showed persistent mitral regurgitation associated with systolic anterior motion of the mitral valve (Figure 7). High velocity flow of more than 3.0 m/sec was recorded by continuous wave Doppler in the left ventricular outflow tract, indicating dynamic subaortic obstruction. One patient had 3+, one patient had 2+, and one patient had 1+ mitral regurgitation in addition to the outflow tract obstruction. During repeat cardiopulmonary bypass, a mitral prosthesis was implanted in two patients and the Carpentier-Edwards ring was removed in one patient. All three patients left the operating room without outflow tract obstruction or significant mitral regurgitation and recovered uneventfully.

In two patients whose postrepair studies showed 2+ mitral regurgitation, no further surgery was performed because they were clinically stable and a second pump run was considered less advantageous than persistence of moderate regurgitation. Although we have no independent corroboration that all decisions made during the course of this study were correct, all 100 patients in this series were discharged from the hospital clinically improved.

Comparison between the real-time visual assessment of mitral regurgitation in the operating room and that derived from off-line measurements from videotape. Figure 8 shows a comparison between the real-time visual estimates of mitral regurgitation in the operating room on a 0–4+ scale and the off-line measurements of the percentage of the left atrial area subtended by the jet. Of 67 cases in whom pre-pump and postpump visual estimates were made with the potential of influencing the operation, the off-line measurements of percentage left atrial area subtended by the jet translated to the same number on

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**FIGURE 5.** Diagram of the prerepair and postrepair intraoperative Doppler color flow mapping assessment of the severity of mitral regurgitation in all 100 patients undergoing valve repair. Single dots, single patients; numbers in circles, number of patients. The postrepair echocardiographic studies mandated further surgery in eight patients, which was done during the same thoracotomy in six patients. MR, persistent mitral regurgitation; SAM, systolic anterior motion of the mitral valve with left ventricular outflow tract obstruction.

**FIGURE 6.** Intraoperative color flow images in successful valve repair. Left: Prerepair echocardiogram showing severe mitral regurgitation filling the entire left atrium (solid arrowheads). Right: No mitral regurgitation on the postrepair echocardiogram; open arrows, the Carpentier-Edwards ring.
the 0–4+ scale in 111 (83%) cases (see the boxes in Figure 8). Thus, the visual assessment is reasonably accurate and has the important advantage of immediacy; the decision to use the Doppler data for intraoperative decision-making followed a substantial learning curve.

Comparison between preoperative angiographic and intraoperative prerepair Doppler data. Figure 9 compares intraoperative prerepair Doppler assessment of mitral regurgitation with the preoperative angiographic assessment of mitral regurgitation in 95 patients performed a mean of 17 days (range, 0–173 days) preoperatively. In 45 patients, the results were identical; in 41 patients, there was a discrepancy of 1+; and in nine patients, there was a discrepancy of 2+. In two patients, no preoperative angiography was performed, and in three patients, the amount of mitral regurgitation on the angiogram could not be interpreted due to arrhythmias. In the eight patients who had 2+ regurgitation by angiography, surgery was indicated because of significant symptoms and at least moderately severe (3+) mitral regurgitation on the preoperative precordial Doppler studies. In addition, five of the eight patients required concomitant coronary or aortic valve surgery.

Correlation between Doppler data derived intraoperatively and that derived by standard transthoracic Doppler studies. Figure 10 (open circles) compares the intraoperative prerepair Doppler assessment of mitral regurgitation and the transthoracic Doppler assessment of mitral regurgitation made in 90 patients in the echocardiographic laboratory a mean of 9 days (range, 0–122 days) preoperatively. In 40 patients, the results were identical; in 40, there was a discrepancy of 1+; and in 10, there was a discrepancy of 2+. Preoperative Doppler studies in the echocardiography laboratory were not performed in 10 patients. Figure 10 (closed circles) shows the comparison between intraoperative postrepair Doppler assessments of mitral regurgitation and postoperative transthoracic Doppler assessments of mitral regurgitation recorded a mean of 7 days (range, 2–40 days) later in 77 patients. In 57 patients, the results were identical; in 19 patients, there was a discrepancy of 1+; and in one patient, there was a discrepancy of 2+. Because the preoperative and prerepair assessments were not simultaneous, the observed differences in the amount of regurgitation were probably due in part to variability in loading conditions. There was no consistent overestimation or underestimation.

![Figure 7](http://circ.ahajournals.org/)

**Figure 7.** Intraoperative color flow images in unsuccessful valve repair. Left: Prerepair echo showing severe 4+ mitral regurgitation (arrowheads). Right: Intraoperative color flow image after attempted valve repair showing persistent mitral regurgitation (arrowheads) with systolic anterior motion of the mitral valve (arrow) adjacent to a high velocity flow disturbance due to dynamic obstruction of the left ventricular outflow tract.

![Figure 8](http://circ.ahajournals.org/)

**Figure 8.** Comparison of off-line semiquantitative versus real-time visual estimates of the severity of mitral regurgitation (MR) on the intraoperative echocardiogram in 67 patients. Visual assessments were made immediately during the operation based on the real-time Doppler color flow images. The percentage of the left atrial (LA) area subtended by the jet averaged from all available image planes was measured off-line from videotapes (see text). The boxes separate the criteria for severity on a 0–4+ scale.
Postoperative transthoracic Doppler studies were not performed in 17 patients, including 15 patients with no regurgitation and two patients with 1+ regurgitation on the intraoperative postrepair studies. In six patients, an operative procedure occurred before transthoracic imaging.

**Discussion**

This study describes a method to assess mitral competency intraoperatively that provides a "safety net" before closure of the chest, ensuring a successful clinical outcome. Surgical repairs that were initially suboptimal occurred in 8% of our 100 patients having mitral reconstruction by a group of surgeons experienced in mitral valve repair. When intraoperative Doppler color flow images show significant problems with the surgical result, our policy is to reinstitute cardiopulmonary bypass to correct the demonstrated abnormalities.

Before intraoperative echocardiography was developed, the assessment of mitral competency could be based only on indirect information. While the patient is still on cardiopulmonary bypass with the heart arrested, the left ventricle can be filled with fluid under pressure (insufflation) while the surgeon looks for fluid leaks into the open left atrium.\(^{15-18}\) Although this provides valuable information about leaflet coaptation, the dynamics of the mitral apparatus in the actively beating heart are quite different than leaflet closure with the left atrium open and the heart flaccid. After discontinuation of cardiopulmonary bypass with the heart beating, mitral regurgitation may be detected by palpation of the left atrial free wall for a systolic thrill and assessment of the left atrial pressure and the size of its V wave.\(^{17,19,20}\) These methods are subjective and dependent on volume status, left atrial size, and chamber compliance.\(^{21}\) Although color flow mapping is also subjective, its superiority was apparent in this series, as it showed 3+ regurgitation in two patients in whom the initial repair appeared to be adequate based on inspection, insufflation, palpation, and the left atrial pressure waveforms, but a second operation was required.

Intraoperative echocardiographic studies have been reported by previous investigators since the first reports of Johnson et al in 1972,\(^{22}\) who measured the E-F slope of the intraoperative mitral M-mode echocardiogram. Intraoperative contrast echocardiography also can assess the severity of mitral regurgitation.\(^{23-25}\) After transmural needle puncture, agitated saline is injected directly into the left ventricle, producing microbubbles observable by standard two-dimensional echocardiography. The severity of mitral regurgitation is judged according to the amount of bubbles seen in the left atrium during the next few beats. By comparison, epicardial Doppler color flow mapping can observe mitral flow dynamics serially over several minutes during rhythms not affected by the testing method itself.

Mindich et al\(^{23}\) and Goldman et al\(^{24,26,27}\) have reported intraoperative contrast echocardiography as an adjunct to mitral and tricuspid valve repair. Two of nine patients with mitral regurgitation who underwent annuloplasty and two of five patients with mitral stenosis who underwent commissurotomy had sufficient mitral regurgitation after repair to warrant reinstitution of cardiopulmonary bypass for further surgery. One additional patient with residual mitral regurgitation detected intraoperatively who did not undergo revision of the repair developed congestive heart failure necessitating reoperation within 3 months. Later, the same group detected residual regurgitation sufficient to require a second pump run in eight of 50 patients undergoing repair.\(^{27}\)

Maurer et al\(^{28}\) and Czer et al\(^{29}\) reported validation of the accuracy of intraoperative Doppler color flow

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**Figures**

**Figure 9.** Comparison of the assessment of the severity of mitral regurgitation by prepump intraoperative Doppler color flow mapping versus preoperative left ventricular angiography in 95 patients.

**Figure 10.** Comparison of the severity of mitral regurgitation by intraoperative Doppler color flow mapping versus standard transthoracic Doppler studies in the echocardiographic laboratory before (○) and after (●) valve repair.
mapping compared with angiography in assessing the severity of mitral regurgitation and the relative inaccuracy of insufflation and V wave amplitude. Of 18 patients having mitral repair for 3+ or 4+ regurgitation, three patients had persistent 3+ regurgitation on the postrepair intraoperative images, although no change was made in the course of the operations. In a similar series, two of 15 patients had 3+ regurgitation, and one required subsequent mitral valve replacement.

Recent studies have highlighted the limitations and inherent assumptions in quantitating valvular regurgitation with Doppler techniques. The spatial extent of a regurgitant jet depends on many instrument- and patient-related factors. Validation of such methods is difficult because the reference standards such as angiography are equally subjective, and the two procedures usually are not performed simultaneously (Figure 9). The methods we used on standard transthoracic studies were based primarily on the distance that the jet extended from the mitral valve. Because of the variability in mitral regurgitant jet shape, however, area algorithms may be preferable for quantitation of severity. By necessity, our decision-making process in the operating room could not depend on time-consuming methods. After a substantial learning curve, we became accustomed to making visual estimates of the extent of the jet in the intraoperative setting. Thereafter, we attempted retrospectively to characterize our visual estimates with an off-line determination similar to a previously published method wherein the percentage of the left atrial area subtended by the jet was measured from stop-frames selected for maximum jet area. The real-time visual estimates correlated well with off-line measurements (Figure 8). Of note, the area ratios derived from frame-by-frame analysis may be larger than is perceived in real-time analysis, wherein the jet distribution from all portions of systole and from many cardiac cycles are visually integrated.

To accurately characterize mitral regurgitation, the left atrium must be interrogated systematically from multiple image planes. Because mitral regurgitation jets may be eccentric, information from one tomographic section may miss the majority of the regurgitant jet due to its unique spatial distribution. In a systematic fashion, we used the four image planes detailed above to ensure that the full extent of the flow disturbance was appreciated.

The usefulness of the intraoperative studies goes beyond detecting residual mitral regurgitation. If the surgeon can understand the mechanism of mitral regurgitation, he or she may be better able to correct it on the first or the second pump run. In three patients, we noted systolic anterior motion of the mitral valve with left ventricular outflow tract obstruction after the initial mitral repair. The intraoperative echocardiographic study characterized this major complication and quantitated the outflow tract gradient with epicardial continuous wave Doppler, allowing successful elimination of the problem by removing the ring in one patient and by replacing the mitral valve in two patients.

Intraoperative echocardiography requires a close cooperation between the cardiologist-echocardiographer and the cardiac surgeon. Neither is uniquely equipped to perform intraoperative imaging without a substantial learning phase. Although the surgeon is more available in the operating room and knowledgeable about open-chest anatomy, he or she is often unfamiliar with handling a transducer and interpreting complex image planes. Likewise, although the cardiologist may be comfortable with tomographic anatomy and Doppler color flow mapping, he or she may not be accustomed to the operating room or to using a transducer on a beating heart. The four basic epicardial image planes available within the surgical field do not include some, such as the apical window, on which the transthoracic Doppler assessment of mitral regurgitation relies heavily.

A reliable intraoperative assessment of mitral regurgitation is particularly useful during the “learning curve” of the surgeon performing the reconstruction. In the early phase of a surgeon’s experience, substantial regurgitation necessitating a second pump run may be quite common; in some reports, the percentage is as high as 67% (two of three), 22% (two of nine), and 17% (three of 18). It is not clear from this study or from available literature what the clinical outcome would be of patients with significant persistent regurgitation after repair. Because we cannot be certain what the course would have been if our six patients had not had second pump runs, we do not know whether our practice of intraoperative echo has reduced the incidence of complications and reoperations, as one recent preliminary report suggests. In a larger series of 309 patients imaged with intraoperative epicardial and transesophageal echocardiography after valve repair for mitral regurgitation, we found a similar 8% incidence of problems requiring a second pump run; immediate correction of these may have contributed to the low 3% incidence of reoperation after 12–60 months (mean, 22 months) of follow-up. The technique of intraoperative Doppler color flow mapping may allow surgeons to be more aggressive in attempting valve conservation surgery, without risking a poor clinical outcome. As we have extended our indications for mitral valve repair to more complex abnormalities and learned the proper indications for techniques such as chordal transfer to the anterior leaflet and more severe rheumatic abnormalities, intraoperative echocardiography remains an integral part of this extension.

Conclusion

Intraoperative Doppler color flow mapping is a reliable method for assessing mitral regurgitation to ensure a successful clinical outcome. The echocardiographic data can correctly identify the adequacy of repair in patients who subsequently have uneventful
postoperative courses and patients who would require early reoperation. Based on intraoperative echocardiography, patients may undergo further mitral surgery during the same thoracotomy. In our institution, intraoperative echocardiography is a routine and essential part of intraoperative decision-making in patients undergoing valve repair for mitral regurgitation.

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