Intraoperative Transesophageal Doppler Color Flow Imaging Used to Guide Patient Selection and Operative Treatment of Ischemic Mitral Regurgitation

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Background. Intraoperative transesophageal Doppler color flow imaging (TDCF) affords the opportunity to assess mitral valve competency immediately before and after cardiopulmonary bypass (CPB). The purpose of this study was to assess the utility of TDCF to assist in the selection and operative treatment of ischemic mitral regurgitation (MR).

Methods and Results. Two hundred forty-six patients undergoing surgery for ischemic heart disease were prospectively studied. All had preoperative cardiac catheterization. Catheterization and pre-CPB TDCF were discordant in their estimation of MR in 112 patients (46%). Compared with patients in whom both techniques agreed in estimation of MR, patients with discordance in MR were more likely to have had unstable clinical syndromes at the time of catheterization (79% versus 40%, p<0.05) or to have received thrombolytics (16% versus 8%, p<0.05). Pre-CPB TDCF resulted in a change in the operative plan with respect to the mitral valve in 27 patients (11%). Because less MR was found by TDCF than catheterization, 22 patients had only coronary bypass grafting when combined coronary bypass and mitral valve surgery had been planned. Because more MR was found by TDCF than catheterization, five patients had combined coronary bypass and mitral valve surgery when coronary bypass alone had been planned. Unsatisfactory results noted by TDCF following mitral valve surgery in five patients resulted in immediate corrective surgery. Cox regression analysis identified residual MR at the completion of surgery to be an important predictor of survival (χ²=21.4) after surgery—more important than patient age (χ²=8.3) or left ventricular ejection fraction (χ²=5.3).

Conclusions. These results indicate that TDCF is useful in guiding patient selection and operative treatment of ischemic MR and that in such patients, intraoperative TDCF should be performed routinely. (Circulation 1991;84:594–604)

Mitral regurgitation occurs in 7–31% of patients with coronary artery disease undergoing cardiac catheterization. The proper management of ischemic mitral regurgitation is crucial to achieve a favorable outcome. An aggressive management approach is supported by data that indicate that the severity of mitral regurgitation directly relates to patient survival and that uncorrected mitral regurgitation after coronary artery bypass grafting is an independent predictor of long-term survival. However, the decision to perform a combined coronary artery bypass and mitral valve procedure carries an operative mortality threefold to 10-fold higher than coronary artery bypass grafting alone.

To optimally decide whether the patient is best served by coronary artery bypass grafting alone or a combined coronary artery bypass and mitral valve procedure, the surgeon must have knowledge about the severity of mitral regurgitation that exists at the time of surgery. This may be quite different than what was detected at cardiac catheterization, especially if the patient has received coronary reperfusion treat-
Doppler color flow imaging is an accurate method to assess the severity of mitral regurgitation.15–17 Both transeosophageal and direct epicardial post–cardiopulmonary bypass imaging have been used to assess the presence of residual mitral regurgitation after mitral valve surgery.8,18–20 The purpose of this study was to prospectively evaluate the utility of intra-operative transeosophageal color flow imaging in guiding patient selection and in the surgical treatment of mitral regurgitation in patients undergoing surgery for ischemic heart disease.

Methods

Patients

Two hundred eighty-six patients undergoing surgery for ischemic heart disease with intraoperative transeosophageal Doppler color flow imaging between July 1987 and February 1989 were studied (Figure 1). These were derived from a total of 1,983 cardiac operations, of which 489 had undergone transeosophageal color flow imaging, and represented 18% of the operations for ischemic heart disease performed during this time period. Excluded from the initial cohort of 286 were 24 patients who had not had a cardiac catheterization within the 3 months before surgery at Duke University Medical Center and 16 patients in whom both pre- and post–cardiopulmonary bypass transeosophageal color flow imaging had not been performed. This left 246 patients for analysis, of which there were 170 men and 76 women with a mean age of 63±10 years (range, 29–82 years).

Transeosophageal Echocardiography

Two-dimensional and Doppler color flow echocardiograms were obtained using a Hewlett-Packard 77020CF imaging unit and a 5.0-MHz single-plane esophageal probe transducer. The probe was placed after induction of general anesthesia and endotracheal intubation. Initial images were obtained before skin incision. The protocol for intraoperative imaging and the specific views obtained have previously been described.21 After pre–cardiopulmonary bypass imaging, more images were obtained during the operation as warranted and, finally, after cardiopulmonary bypass before skin closure. Studies were recorded on 1/2-in. high-fidelity videotape for later review.

Echocardiographic Interpretations

Preliminary interpretations of all studies during the surgical procedure were rendered by one of three attending anesthesiologists who have a combined experience of performing and interpreting more than 2,000 transeosophageal echocardiograms. Consultation from senior cardiology staff was available as needed and occurred during 21 procedures (8.5%). All operative decisions were based on real-time information. Videotapes of all studies were then reviewed off line. Interobserver variability between on-line and off-line assessment of mitral regurgitation was assessed. Grading of pre– and post–cardiopulmonary bypass mitral regurgitation, left ventricular function, and other abnormalities were made by consensus agreement of two observers blinded to the results of preoperative cardiac catheterization, operative results, and postoperative course. Ventricular function was evaluated from short-axis views using qualitative criteria as previously described.22

Transeosophageal Color Flow Imaging

Doppler color flow imaging was performed using velocity-variance maps. The primary colors of red, blue, and green were used to express the direction, velocity, and variance of blood flow superimposed on the two-dimensional image. Abnormal flows were recognized by color-encoded multidirectional, aliased, and turbulent jets. Two-dimensional imaging gain and reject settings were set so that the cardiac chambers contained no signal. Color gains were adjusted to the highest level that produced a color signal that was contained only within the cardiac chambers without background noise.

Mitral regurgitation was visually estimated on a semiquantitative scale according to the maximum length and width of the abnormal jet relative to the left atrium. The scan plane yielding the least left atrial foreshortening and the largest color flow jet was used to grade regurgitation as follows: 0 indicated no regurgitation, 1+ was assigned if the regurgitant jet was less than one third of both the length and width of the left atrium; 2+ if the jet was one third to one half of the length and width of the left atrium; 3+ if the jet was one half to two thirds of the length and width of the left atrium; and 4+ if the jet exceeded two thirds of the length and width of the left atrium (Figure 2). These criteria were applied to central and eccentric regurgitant jets having proportional lengths and widths, which were present in 213 studies before bypass (87%) and in 191 studies after bypass (78%). When eccentric jets having lengths and widths disproportionate to one another were noted, the maximal severity of regurgita-
tion based on either length or width was assigned and then reduced by one degree.

When pre–cardiopulmonary bypass mitral regurgitation assessed by transesophageal color flow imaging was less than that assessed at cardiac catheterization and the mean arterial pressure was less than 90 mm Hg or more than 15 mm Hg below that at preoperative cardiac catheterization, or the pulmonary capillary wedge pressure was less than 12 mm Hg, volume loading through the aortic cannula or phenylephrine (50–300 μg) was administered, and mitral regurgitation was reassessed. After the operation, mitral regurgitation was assessed in the same manner as described above. If multiple runs on cardiopulmonary bypass were required, mitral regurgitation was assessed after each run.

Cardiac Catheterization

Cardiac catheterization was performed by standard Judkins techniques 1–90 days (mean, 10±18 days) before surgery. This included coronary arteriography, left ventriculography, and central arterial and left ventricular (LV) manometry. Significant coronary disease was defined as a greater-than-50% luminal diameter narrowing of a major epicardial artery by visual estimate.23 LV ejection fraction was determined by biplane ventriculography using the modified area–length method.24 Other procedures such as blood oximetry, aortography, and right-heart pressure assessments were done at the discretion of the attending cardiologist.

Mitral regurgitation was assessed from biplane ventriculography by consensus agreement of two experienced angiographers on a 0–4+ scale by the Sellers criteria.25 Care was taken to exclude catheter-induced mitral regurgitation, but the volume and rate of contrast infusion for ventriculography were at the discretion of the attending physician. If multiple catheterizations had been performed, the results of the study closest to the time of surgery were used. No patient underwent coronary angioplasty between the time of the last diagnostic catheterization and surgery.

Surgery

All patients were seen before surgery by the attending surgeon. At that time, a determination of the planned surgical procedure was made based on the results of all available preoperative tests and clinical evaluation. All patients had radial and pulmonary artery catheters placed for hemodynamic monitoring before cardiopulmonary bypass.

All operations were for ischemic heart disease, and included 182 isolated coronary artery bypass operations (74%), 30 combined coronary artery bypass and mitral valve operations (12%) (mitral valve repair, 21; prosthetic mitral valve replacement, nine), nine combined coronary artery bypass and LV aneurysm resections (4%), six combined coronary artery bypass and postinfarction ventricular septal defect repairs (2%), and 19 operations involving a variety of valvular or congenital procedures (8%), all combined with coronary artery bypass grafting. The mitral valve repairs consisted of four annular rings and four annular and leaflet repairs by the method of Carpentier,26 and 13 Kay annuloplasties.27 For all mitral valve procedures, the etiology of mitral valve disease was determined by direct inspection as due to papillary muscle dysfunction (n=19), annular dilatation (n=11), or papillary muscle rupture (n=0).28

The attending surgeon had full knowledge of the results of both pre– and post–cardiopulmonary bypass transesophageal imaging. Any change in the preoperative plan or decisions to correct defects recognized after the initial run on cardiopulmonary bypass were made by the attending surgeon.

Data Collection and Analysis

Baseline clinical data, the results of cardiac catheterization, operative information, and follow-up information were collected prospectively by the Duke University Cardiovascular Data Bank.29 At the time of catheterization, patients were categorized as having either unstable coronary syndromes (acute myocardial infarction or unstable angina with acute electrocardiographic changes) or stable coronary syndromes (asymptomatic, stable angina, or progressive angina but without electrocardiographic changes). Thrombolytic agents administered within the 24 hours before or after cardiac catheterization were so noted. Follow-up status was assessed at hospital discharge, 6 months and 1 year after surgery, and yearly thereafter, as previously reported, and was 100% complete.23 The mean duration of follow-up was 310±160 days (range, 1–840 days). Patient status as alive or dead and any further cardiac surgery were noted.

The amount of mitral regurgitation detected by pre–cardiopulmonary bypass transesophageal color

\[ LA, \text{ left atrium; RV, right ventricle; LV, left ventricle.} \]
flow imaging was compared with the amount noted by preoperative cardiac catheterization. If phenylephrine or volume loading was administered, the amount of mitral regurgitation subsequent to these maneuvers was compared with that at cardiac catheterization. The influence of transesophageal imaging on the planned operation was noted by the attending anesthesiologist at the time of surgery on a standard data collection form. A change in the planned operative procedure was considered to have resulted if a coronary artery bypass operation alone had been planned and a combined coronary artery bypass and mitral valve procedure was performed, or if a combined coronary artery bypass and mitral valve procedure had been planned and only a coronary artery bypass operation was performed.

Other findings detected by pre–cardiopulmonary bypass transesophageal imaging that resulted in a change in the planned operation were also noted. The effect of post–cardiopulmonary bypass imaging on the conduct of the operation, particularly as it related to a repeat run on cardiopulmonary bypass due to significant residual mitral regurgitation or decisions made due to recognition of LV dysfunction, was noted. The amount of mitral regurgitation after completion of the operation was assessed. Postoperative LV function was also assessed and compared with pre–cardiopulmonary bypass LV function as either unchanged, better, or worse.

Statistics

Patient groups were compared with respect to continuous variables using the Wilcoxon rank sum test and for discrete variables using \( \chi^2 \) analysis. A \( p < 0.05 \) was considered significant. Agreement in the amount of mitral regurgitation assessed by transesophageal imaging with cardiac catheterization as well as interobserver agreement was assessed by the weighted Kappa statistic. \(^{30}\) \( \kappa \) values equal to 1.00 indicate perfect agreement, those over 0.75 indicate very good agreement beyond chance, and if \( \kappa \) equals 0, then no or random agreement exists. Survival curves were derived from Kaplan-Meier survival estimates. \(^{31}\) Survival data for the groups were compared with the Cox proportional hazard model \(^{32}\) using the SAS PHGLM procedure. \(^{33}\) The variables noted in Table 4 were examined by Cox model analysis for their relative importance in influencing survival.

Results

Prebypass Mitral Regurgitation

The severity of mitral regurgitation assessed by pre–cardiopulmonary bypass transesophageal color flow imaging is compared with that assessed by preoperative cardiac catheterization in Figure 3. The \( \kappa \) value of 0.29 indicates a poor level of agreement between the two tests. There were 28 patients (11%) in whom the level of discordance was more than one grade. By comparison, in patients we have previously reported with primary valvular heart disease without coronary artery disease, the agreement in mitral regurgitation grade assessed by preoperative cardiac catheterization and pre–cardiopulmonary bypass transesophageal color flow imaging was excellent, with a \( \kappa \) value of 0.84. \(^{21}\) The interobserver agreement for mitral regurgitation assessed by pre–cardiopulmonary bypass transesophageal color flow imaging between real-time interpretations and off-line review was excellent, with complete concordance noted in 223 (91%), disagreement by one grade in 21 (8%), two grades in two (0.8%), and more than two grades in none, yielding a \( \kappa \) value of 0.85.

Concordance versus Discordance

Clinical characteristics of patients who exhibited concordance in the severity of mitral regurgitation assessed by pre–cardiopulmonary bypass transesophageal color flow imaging and cardiac catheterization are compared with those exhibiting discordance in Table 1. Both groups were similar in terms of age, the extent of coronary artery disease, LV ejection fraction, and the need for emergency surgery. The time from catheterization to surgery was also similar between both groups and was not different between patients with differing degrees of discordance. Both groups had lower mean arterial pressures and pulmonary capillary wedge pressures at the time of pre–cardiopulmonary bypass transesophageal color flow imaging.
TABLE 1. Baseline Characteristics for Concordant Versus Discordant Patients

<table>
<thead>
<tr>
<th></th>
<th>Concordant (n=134)</th>
<th>Discordant (n=112)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>63±9</td>
<td>64±10</td>
</tr>
<tr>
<td>Clinical syndrome</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unstable</td>
<td>53 (40%)</td>
<td>88 (79%)*</td>
</tr>
<tr>
<td>Thrombolytic agents</td>
<td>11 (8%)</td>
<td>18 (16%)*</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>47±12</td>
<td>45±14</td>
</tr>
<tr>
<td>CAD vessels (No.)</td>
<td>2.4±0.7</td>
<td>2.5±0.7</td>
</tr>
<tr>
<td>LVEDPc (mm Hg)</td>
<td>15±8</td>
<td>18±8*</td>
</tr>
<tr>
<td>Time from catheterization to surgery</td>
<td>10±17</td>
<td>10±19</td>
</tr>
<tr>
<td>Emergency surgery</td>
<td>16 (12%)</td>
<td>17 (15%)</td>
</tr>
<tr>
<td>LVEDPc−PCWPs (mm Hg)</td>
<td>3.8±6.8</td>
<td>1.4±7.7*</td>
</tr>
<tr>
<td>MAPc−MAPs (mm Hg)</td>
<td>17±14</td>
<td>19±11</td>
</tr>
</tbody>
</table>

Values represent mean±1 SD or number of patients (% of total group).

*p<0.05 concordant vs. discordant.

LVEF, left ventricular ejection fraction measured at catheterization; CAD, coronary artery disease; LVEDPc, left ventricular end-diastolic pressure measured at catheterization; PCWPs, pulmonary capillary wedge pressure measured before cardiopulmonary bypass; MAPc, mean arterial pressure measured at catheterization; MAPs, mean arterial pressure measured before cardiopulmonary bypass.

flow imaging than the mean arterial pressure and LV end-diastolic pressure measured at the time of cardiac catheterization. Mean arterial pressures were, however, decreased to equal degrees in both groups. As many of the discordant group had received either volume loading or phenylephrine, the difference between their LV end-diastolic pressure at catheterization and the pulmonary capillary wedge pressure measured at surgery was even less than in the concordant group.

Patients exhibiting discordance were more likely to have had an unstable clinical syndrome (acute myocardial infarction or unstable angina with electrocardiographic changes) at the time of cardiac catheterization, to have received thrombolytic therapy, and had higher LV end-diastolic pressures at the time of catheterization than the concordant group.

Impact of Transesophageal Echocardiography on the Operative Plan

The effect of the pre–cardiopulmonary bypass transesophageal color flow assessment of mitral regurgitation on the planned operation is indicated in Figure 4. Although the operative plan as it related to the mitral valve was followed in all 134 patients having concordance in estimates of mitral regurgitation severity, the operative plan was altered in 27 patients (11%). In 22 cases, a planned combined coronary artery bypass and mitral valve procedure was changed to a coronary artery bypass procedure alone as a result of finding less mitral regurgitation by transesophageal color flow imaging than had been present at cardiac catheterization. Conversely, in five cases, a planned coronary artery bypass operation alone was changed to a combined coronary artery bypass and mitral valve procedure as a result of detecting more mitral regurgitation by transesophageal color flow imaging than had been present at cardiac catheterization.

Other operative decisions based on intraoperative transesophageal echocardiography are indicated in Table 2. In addition to the impact on mitral valve surgery, in four cases pre–cardiopulmonary bypass imaging was useful in other ways, resulting in a modification of the original operative plan. Post–cardiopulmonary bypass imaging identified five cases in which the initial operative results were unsatisfactory, resulting in immediate reoperation. In six instances post–cardiopulmonary bypass imaging was felt to be instrumental in the recognition of LV dysfunction, prompting either institution of hemodynamic support or a revision of a bypass graft.

Patient Outcome

Outcome of patient groups is indicated in Figure 5. Patients who underwent only coronary artery bypass grafting, whether planned or prompted by the results

![Figure 4](https://circ.ahajournals.org/)

**FIGURE 4.** Effect of discordance between ventriculographic and transesophageal echocardiographic assessment of mitral regurgitation on the operation performed. Individual patients are indicated by transparent and darkened circles and squares as noted in key. MR, mitral regurgitation; TDCF, transesophageal Doppler color flow imaging; CABG, coronary artery bypass graft surgery; MV, mitral valve surgery.
TABLE 2. Other Use of Intraoperative Transesophageal Echocardiography

<table>
<thead>
<tr>
<th>Number</th>
<th>Finding</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before CPB</td>
<td>3 ASD—Detected</td>
<td>Repaired</td>
</tr>
<tr>
<td></td>
<td>1 VSD—Identified multiple defect sites</td>
<td>Guided repair site</td>
</tr>
<tr>
<td>After CPB</td>
<td>4 Residual MR after initial mitral surgery</td>
<td>Repeat CPB and further mitral surgery</td>
</tr>
<tr>
<td></td>
<td>1 LV outflow tract obstruction after mitral repair</td>
<td>Revised mitral repair to prosthetic replacement</td>
</tr>
<tr>
<td></td>
<td>5 LV dysfunction</td>
<td>Institution of hemodynamic support</td>
</tr>
<tr>
<td></td>
<td>1 LV dysfunction</td>
<td>Revision of bypass graft</td>
</tr>
</tbody>
</table>

CPB, cardiopulmonary bypass; ASD, atrial septal defect; VSD, ventricular septal defect; MR, mitral regurgitation; LV, left ventricle.

of transesophageal color flow imaging, had equivalent operative mortality rates (6% versus 5%, respectively) and equivalent long-term survival rates ($p=0.80$). No patient in whom a combined mitral valve and coronary bypass procedure was planned but later modified to only a coronary bypass procedure alone required a repeat operation for mitral incompetence. For patients undergoing planned combined coronary bypass and mitral valve procedures, operative mortality was 13%, but long-term survival was 81%. Among the five patients who had an unplanned combined coronary bypass and mitral valve operation, no patient experienced operative or late death, but the small number of patients in this group does not permit statistical comparisons.

Other potential contributors to postoperative early and late mortality that might account for survival differences between groups are shown in Table 3. All four subgroups had equivalent ages, gender distributions, LV ejection fractions, extent of coronary artery disease, frequency of emergency surgery, post–cardiopulmonary bypass LV dysfunction, and follow-up times. Patients undergoing coronary artery bypass grafts alone, whether planned or unplanned, had an equal proportion of ventricular septal defect repairs and LV aneurysm resections. All five patients who had unplanned combined coronary artery bypass and mitral valve procedures underwent mitral valve repair versus 16 in the planned combined group who had mitral valve repair, a difference not significantly different ($p=0.27$). Patients undergoing either unplanned coronary artery bypass grafting alone or unplanned combined coronary artery bypass and mitral valve procedures more frequently had unstable clinical syndromes than those who had planned coronary artery bypass grafting or planned combined procedures.

Residual mitral regurgitation and LV dysfunction identified by post–cardiopulmonary bypass transesophageal imaging were important determinants of postoperative survival. As shown in Figure 6, of 219 patients judged to have 0 or 1+ mitral regurgitation at the completion of the operation, long-term survival was significantly improved over the 27 patients who had 2+ and 3+ mitral regurgitation at the completion of the operation ($p<0.001$). Likewise, as shown in Figure 7, patients with post–cardiopulmonary bypass LV dysfunction had worse survival than patients in whom LV function was unchanged or improved in comparison with the pre–cardiopulmonary bypass examination ($p<0.001$).

As indicated in Table 4, the amount of mitral regurgitation that was present at the completion of the operation was the most important variable influencing survival after surgery. Notably, its predictive value for survival exceeded that of age, extent of coronary artery disease, and LV ejection fraction.

Discussion

Selection of Patients for Mitral Valve Surgery

Mitral regurgitation occurs in up to 30% of all patients with coronary artery disease1–3 and in more than 50% of patients with acute myocardial infarction.34 If surgical revascularization is considered, knowledge of mitral valve competency is mandatory before surgery. The severity of mitral regurgitation closely relates to both operative mortality and long-term survival after coronary artery bypass surgery.3,5,6 Uncorrected mitral regurgitation after coronary ar-

FIGURE 5. Survival curves for surgical subgroups. Kaplan-Meier survival estimates for the four main surgical subgroups of patients in the study. CABG, coronary artery bypass graft surgery; MV, mitral valve surgery.
TABLE 3. Operative Risk Factors for Surgical Subgroups

<table>
<thead>
<tr>
<th></th>
<th>CABG planned/</th>
<th>MV+CABG planned/</th>
<th>MV+MV+CABG planned/</th>
<th>CABG planned/</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CABG done</td>
<td>MV+CABG done</td>
<td>CABG done</td>
<td>MV+CABG done</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>63±10</td>
<td>65±8</td>
<td>65±9</td>
<td>62±12</td>
</tr>
<tr>
<td>Sex (male:female)</td>
<td>14±50</td>
<td>13±9</td>
<td>10±15</td>
<td>3±2</td>
</tr>
<tr>
<td>Unstable clinical syndrome</td>
<td>101±52%</td>
<td>21 (95%)</td>
<td>14 (56%)</td>
<td>5 (100%)</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>46±14</td>
<td>47±10</td>
<td>47±13</td>
<td>44±7</td>
</tr>
<tr>
<td>CAD vessels (No.)</td>
<td>2.5±0.7</td>
<td>2.6±0.6</td>
<td>2.0±0.9</td>
<td>2.4±0.5</td>
</tr>
<tr>
<td>LVEDPc (mm Hg)</td>
<td>16±8</td>
<td>20±9</td>
<td>20±10</td>
<td>18±10</td>
</tr>
<tr>
<td>Emergency surgery</td>
<td>27 (14%)</td>
<td>2 (9%)</td>
<td>4 (16%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Additional surgery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+ VSD repair</td>
<td>5 (3%)</td>
<td>1 (5%)</td>
<td>0.62</td>
<td>0</td>
</tr>
<tr>
<td>+LV aneurysm resection</td>
<td>9 (5%)</td>
<td>0 (0%)</td>
<td>0.31</td>
<td>0</td>
</tr>
<tr>
<td>Mitral valve surgery</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MV repair</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-CPB LV dysfunction</td>
<td>30 (15%)</td>
<td>3 (14%)</td>
<td>0.75</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Time to follow-up (days)</td>
<td>310±159</td>
<td>303±161</td>
<td>0.73</td>
<td>300±151</td>
</tr>
</tbody>
</table>

Values represent mean±1 SD or number of patients (% of subgroup). CABG, coronary artery bypass grafting; MV, mitral valve surgery; LVEF, left ventricular ejection fraction measured at catheterization; CAD, coronary artery disease; LVEDPc, left ventricular end-diastolic pressure measured at catheterization; VSD, ventricular septal defect; LV, left ventricular; CPB, cardiopulmonary bypass.

*p* values represent comparisons of CABG planned/CABG done with MV+CABG planned/CABG done and MV+CABG planned/MV+CABG done.

tary bypass grafting is an independent risk factor for long-term survival. While these data support aggressive surgical management of ischemic mitral regurgitation, performing a combined coronary artery bypass and mitral valve procedure subjects the patient to an operative risk threefold to 10-fold higher than coronary artery bypass grafting alone. Thus, properly selecting which patients are best served by coronary artery bypass grafting alone or combined coronary artery bypass and mitral valve procedures is a frequent and critical concern.

The main finding of this study is that by applying transesophageal Doppler color flow imaging to assess mitral regurgitation immediately before surgery, 27 patients (11%) had an alteration in the operation that had been planned based on the cardiac catheterization estimate of mitral regurgitation. In 22 cases, this resulted in saving the patient from an unnecessary mitral valve procedure and consequently exposure to a procedure with a higher operative mortality. In five cases it resulted in incorporation of a mitral valve procedure to coronary artery bypass grafting. Thus, attention was drawn to the existence of significant mitral regurgitation at the time of surgery, which would have otherwise been neglected, placing the patient at risk for lower long-term survival.

Analysis of the survival data among the surgical subgroups further indicates that an alteration in the

**FIGURE 6.** Survival curves related to postoperative mitral regurgitation. Kaplan-Meier survival estimates for groups of patients according to the degree of mitral regurgitation assessed by post–cardiopulmonary bypass transesophageal imaging at the completion of the operation. Post-CPB MR, post–cardiopulmonary bypass mitral regurgitation.

**FIGURE 7.** Survival curves related to postoperative left ventricular function. Kaplan-Meier survival estimates for groups of patients according to left ventricular function assessed by post–cardiopulmonary bypass transesophageal imaging. Groups shown had either unchanged or improved left ventricular function vs. worsened left ventricular function compared with the pre–cardiopulmonary bypass imaging. Post-CPB, post–cardiopulmonary bypass.
TABLE 4. Variables Influencing Survival

<table>
<thead>
<tr>
<th>Variable</th>
<th>( \chi^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post–CPB MR</td>
<td>21.4</td>
</tr>
<tr>
<td>Age</td>
<td>8.3</td>
</tr>
<tr>
<td>Post–CPB wall motion</td>
<td>6.1</td>
</tr>
<tr>
<td>LVEF</td>
<td>5.3</td>
</tr>
<tr>
<td>Number of diseased vessels</td>
<td>4.8</td>
</tr>
<tr>
<td>Pre–CPB MR</td>
<td>4.7</td>
</tr>
</tbody>
</table>

CPB, cardiopulmonary bypass; MR, mitral regurgitation; LVEF, left ventricular ejection fraction.

\( p<0.05; \) data derived from Cox model analysis of long-term survival characteristics (\( n=246 \)).

operative plan based on transesophageal imaging did not result in a lower operative or long-term survival. Patients undergoing coronary artery bypass grafting, whether planned or prompted by the results of transesophageal imaging, had equivalent survival rates. Patients in both groups had similar profiles for operative risk factors. The relatively high operative mortality in both groups of patients was likely a result of a preselection of high-risk patients for intraoperative transesophageal imaging, reflected in the relatively high mean age, low LV ejection fractions, high frequency of unstable clinical syndromes, and inclusion of patients undergoing other high-risk operations such as ventricular septal defect repairs and LV aneurysm resections in both groups. In fact, patients who had their operation modified to a coronary artery bypass graft alone may have been a somewhat higher operative risk group than those undergoing planned coronary artery bypass operations alone by virtue of the fact that they had a higher frequency of unstable clinical syndromes and higher LV end-diastolic pressures than those having the planned operation.

Likewise, for patients undergoing combined coronary artery bypass and mitral valve procedures, whether planned or prompted by the results of transesophageal imaging, survival rates were similar. Although the number of patients in both groups was small, surgical risk factors were similar between these groups as well, with the exception of a higher frequency of unstable clinical syndromes in the group having their operation modified by the results of transesophageal imaging. In fact, none of the five patients in whom a modified operation was performed died in follow-up. This may partly be contributed to by the fact that all of these patients underwent mitral valve repairs, for which an improved survival rate compared with mitral valve replacement has been reported.35-36

Discordance in Estimation of Mitral Regurgitation

Previous studies comparing Doppler techniques to cardiac catheterization for estimation of mitral regurgitation have reported good correlations.15-17,37 This may be somewhat surprising, given that each of the techniques has unique technical limitations and differences in how regurgitation is assessed and graded. Angiography renders a projectional image of the cardiac chambers in which the assessment of regurgitation depends on dye accumulation over several heartbeats. It is both operator and observer dependent. Arrhythmias, catheter position, the pressure and volume of injectate, the left atrial and ventricular chamber sizes, and LV systolic function will all affect the grading of regurgitation severity.38,39 Although the Sellers criteria to estimate mitral regurgitation were used,25 no attempt was made in this study to supervise the performance or interpretation of angiograms, which may have contributed to the observed discrepancies between catheterization and Doppler estimates of mitral regurgitation.

Of equal concern are the technical considerations in Doppler color flow imaging, such as two-dimensional and Doppler gain settings, the angle of interrogation, and the display format, all of which can affect the size of the regurgitant jet.37,40 Thus, consistency in equipment, control settings, and display formats must be maintained, as was done throughout the course of this study. Furthermore, while a transducer orientation parallel to blood flow is critical for conventional pulsed and continuous wave Doppler assessment of peak velocity because color signals are encoded as mean velocities, this is not as critical.40 Because the transesophageal probe is immediately behind the left atrium and mitral valve and may be optimally positioned to interrogate regurgitant flow through the mitral valve, transesophageal imaging may be better suited to assess mitral regurgitation than either chest wall or epicardial imaging.

Another consideration is the criteria applied to grade severity of regurgitation. A variety of criteria have previously been proposed, none of which result in complete agreement between Doppler and angiographic estimates of mitral regurgitation. Disagreement of the two techniques may be especially pronounced when eccentric regurgitant jets are encountered. However, previous work indicates that correlation of catheterization and Doppler grading of mitral regurgitation severity is optimized by taking into account both the length and width of the color jet and relating it to the left atrial size, as was done in this study.41 There is little interobserver and intraobserver variability or day-to-day variability in mitral regurgitation assessed by Doppler color flow imaging when patients with ischemic heart disease are excluded.42,43 Previous investigators have reported good correlations using grading criteria similar to those used in this study between catheterization estimates of mitral regurgitation and those obtained using intraoperative Doppler color flow imaging performed from both direct epicardial and transesophageal approaches.8,20

Of note, when these grading criteria were applied, there was little interobserver variability, and we have previously noted a good correlation with catheterization estimates of mitral regurgitation in patients without ischemic heart disease.21 However, it should be noted that most regurgitant jets in this study were central with proportional lengths and widths. Little
information exists regarding how eccentric or disproportionate jets are best graded.

Given these considerations, it appears likely that in most patients exhibiting discordance in the amount of mitral regurgitation present at catheterization and that detected by pre-cardiopulmonary bypass imaging, there had indeed been a change in the amount of mitral regurgitation between the time of the two studies. This difference could not be attributed to any difference in baseline clinical characteristics between discordant and concordant patients. While loading conditions were different between the time of catheterization and transesophageal imaging, the mean arterial pressures were reduced to equal degrees in patients exhibiting discordance and concordance in mitral regurgitation. The difference in LV filling pressures between pre-cardiopulmonary bypass transesophageal imaging and catheterization was, in fact, less in the group of patients with discordance than concordance, primarily because in the discordant group, an effort to increase both preload and afterload through volume infusion or phenylephrine was made before an estimation of mitral regurgitation severity.

The only difference between the two groups was that patients with discordance were more likely to have had an unstable clinical syndrome at the time of catheterization or to have received thrombolytic therapy before surgery. In the era of coronary reperfusion, this is an important observation. The syndrome of fluctuating mitral regurgitation as a result of intermittent ischemia is well known. Intermittent coronary occlusion resulting from a variable combination of thrombosis and vasocostriction is well described in both acute myocardial infarction and unstable angina. Mitral regurgitation severity has been shown to be altered with coronary reperfusion achieved either through thrombolytic therapy or percutaneous angioplasty. While in most cases mitral regurgitation will improve after reperfusion therapy, in some patients it may worsen. The findings of this study indicate that in patients having received thrombolytic therapy or undergoing cardiac catheterization at a time during an unstable coronary syndrome, if coronary artery surgery is necessary, a decision regarding mitral valve surgery be made on the basis of an assessment of mitral regurgitation at or near the time of surgery, rather than based on the results of the initial catheterization. A carefully and skillfully performed pre-cardiopulmonary bypass transesophageal Doppler color flow examination can reliably be used to help make this determination.

Additional Value of Intraoperative Echocardiography

In addition to modification of the operative plan with respect to the mitral valve in 27 patients, pre-cardiopulmonary bypass transesophageal imaging was useful in modifying or guiding the operative approach in four additional patients. In three cases, a previously unsuspected atrial septal defect was detected and repaired. In one case, a ventricular septal defect was identified with two discrete sites of rupture, permitting repair of both sites. These observations extend those made previously by our group and others regarding the utility of intraoperative echocardiography in guiding the operative plan in patients undergoing operations to correct valvular heart disease and congenital heart disease.

The value of post-cardiopulmonary bypass echocardiographic imaging to evaluate the results of mitral valve surgery is now well documented. While initial experience was with simple anatomic imaging, recent experience with contrast echocardiography and most recently Doppler color flow imaging indicates that this method is superior to other methods to assess mitral valve competency after surgery. As was shown in this study and previously reported by our group and others, residual mitral regurgitation after mitral valve repair or replacement is associated with an increased postoperative mortality and morbidity. It is in fact the most important predictor of survival after surgery. Thus, it is noteworthy that in four patients, transesophageal imaging identified patients with significant residual regurgitation, which prompted immediate reoperation.

No patient left the operating room with 4+ mitral regurgitation and only six of 246 (2%) left the operating room with 3+ mitral regurgitation. In these six patients, the surgeon had considered further surgery to the mitral valve either impossible or a prohibitive risk. As expected, only three of these patients are still alive. What is somewhat surprising is that even patients with mitral regurgitation assessed at 2+ on the completion of the operation had an adverse postoperative course. This group also experienced adverse postoperative survival, with two patients having returned for corrective mitral valve operations. These results would indicate that an attempt should be made to correct even moderate levels of mitral regurgitation after coronary artery bypass surgery alone or combined coronary artery bypass and mitral valve procedures.

Post-cardiopulmonary bypass transesophageal imaging detected one patient with LV outflow obstruction after mitral valve repair, resulting in an immediate revision of the repair to a mitral valve prosthetic replacement. This complication has been reported in up to 10% of patients undergoing mitral valve repair and may be responsible for postoperative morbidity. By performing post-cardiopulmonary bypass imaging, it is possible to detect this complication and correct it before leaving the operating room by revision of the repair or prosthetic valve replacement.

Post-cardiopulmonary bypass imaging was primarily responsible for the recognition of six cases of LV dysfunction for which specific therapeutic measures were used. Intraoperative transesophageal echocardiography is more sensitive than ST segment or hemodynamic changes to detect myocardial injury. Intraoperative regional wall motion abnormalities occur in 30–50% of patients undergoing coronary artery bypass grafting. In 6–8% the
abnormalities may persist, indicating an intraoperative myocardial infarction. Worsened global or regional LV function was noted in 36 of 246 patients (14%) at the completion of the operation, and identified patients who had a decreased postoperative survival in comparison with patients who had either no change or no improvement in LV function at the completion of the operation. We have also previously noted the poor prognostic value of this finding in patients undergoing primary valve procedures.\textsuperscript{21}

Conclusions

Intraoperative transesophageal Doppler color flow imaging is a valuable diagnostic modality in patients undergoing operations for ischemic heart disease. Results of transesophageal imaging can be used to guide patient selection and operative treatment of ischemic mitral regurgitation. Pre-cardiopulmonary bypass transesophageal imaging should be used in any patient in whom there is uncertainty regarding the severity of mitral regurgitation existing at the time of surgery, in patients who had mitral regurgitation assessed at the time of an unstable ischemic syndrome, or in patients who have received thrombolytic therapy before surgery. Post-cardiopulmonary bypass imaging is useful in identifying residual mitral regurgitation and LV dysfunction following surgery. Recognition of either should prompt immediate corrective measures, as both findings identify patients at increased risk for postoperative mortality.

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