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Intraoperative Evaluation of Mitral Valve Regurgitation and Repair by Transesophageal Echocardiography: Incidence and Significance of Systolic Anterior Motion

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Objectives. This study was designed to delineate the utility and results of intraoperative transesophageal echocardiography in the evaluation of patients undergoing mitral valve repair for mitral regurgitation.

Background. Mitral valve reconstruction offers many advantages over prosthetic valve replacement. Intraoperative assessment of valve competence after repair is vital to the effectiveness of this procedure.

Methods. Intraoperative transesophageal echocardiography was performed in 143 patients undergoing mitral valve repair over a period of 23 months. Before and after repair, the functional morphology of the mitral apparatus was defined by two-dimensional echocardiography; Doppler color flow imaging was used to clarify the mechanism of mitral regurgitation and to semiquantitate its severity.

Results. There was significant improvement in the mean mitral regurgitation grade by composite intraoperative transesophageal echocardiography after valve repair (3.6 ± 0.8 to 0.7 ± 0.7; $p < 0.00001$). Excellent results from initial repair with grade ≤1 residual mitral regurgitation were observed in 88.1% of patients. Significant residual mitral regurgitation (grade ≥3) was identified in 11 patients (7.7%); 5 underwent prosthetic valve replacement, 5 had revision of the initial repair and 1 patient had observation only. Of the 100 patients with a myxomatous mitral valve, the risk of grade ≥3 mitral regurgitation after initial repair was 1.7% in patients with isolated posterior leaflet disease compared with 22.5% in patients with anterior or bileaflet disease.

Severe systolic anterior motion of the mitral apparatus causing grade 2 to 4 mitral regurgitation was present in 13 patients (9.1%) after cardiopulmonary bypass. In 8 patients (5.6%), systolic anterior motion resolved immediately with correction of hyperdynamic hemodynamic status, resulting in grade ≤1 residual mitral regurgitation without further operative intervention.

Transthoracic echocardiography before hospital discharge demonstrated grade ≤1 residual mitral regurgitation in 86.4% of 132 patients studied. A significant discrepancy (>1 grade) in residual mitral regurgitation by predischarge transthoracic versus intraoperative transesophageal echocardiography was noted in 17 patients (12.9%).

Conclusions. Transesophageal echocardiography is a valuable adjunct in the intraoperative assessment of mitral valve repair.

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Mitral valve reconstruction is becoming increasingly favored over prosthetic replacement for a variety of lesions causing mitral regurgitation (1–8). Mitral valve repair has been associated with both lower operative (9,10) and late (3–5) mortality rates compared with mitral valve replacement, with similar improvement of symptoms postoperatively (4,5) and the long-term need for reoperation (5,7). Moreover, mitral valve repair minimizes potential complications associated with mitral prostheses, such as thromboembolism (3,4,8), bleeding secondary to anticoagulant therapy (4,8), infectious endocarditis (4,5), and preserves the mitral support apparatus and hence, left ventricular systolic performance (11–13).

Paramount to the effectiveness of mitral valve reconstruction is the intraoperative assessment of mitral competence after repair. To this end, multiple techniques with varying physiologic relevance have been employed (14–17). More recently, several methods using intraoperative echocardiography have been described. These include contrast echocardiography with either epicardial (18) or transesophageal (19) imaging and epicardial (20–23) and transesophageal (24,25) echocardiography with Doppler color flow mapping.

In this report, we describe our experience with transesophageal echocardiography in the intraoperative evaluation of 143 mitral valve repair procedures for mitral regurgitation performed at the Mayo Clinic.

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Table 1. Etiology of Mitral Valve Regurgitation

	No. of Patients (%)
Myxomatous degeneration (prolapse with or without flail)	100 (70)
Ischemic left ventricular dysfunction	18 (12)
Cleft mitral valve leaflet	9 (6)
Rheumatic disease	4 (3)
Miscellaneous	12 (8)
Total	143 (100)

Table 2. Cardiac Operations Performed

	No. of Patients (%)
MV repair	86 (60)
MV repair + CABG	34 (24)
MV repair + AVR	9 (6)
MV repair + ASD repair	6 (4)
MV repair + TV repair	3 (2)
MV repair + TV repair + AVR	2 (1)
MV repair + LV aneurysmectomy + CABG	2 (1)
Repeat MV repair	1 (1)

ASD = atrial septal defect; AVR = aortic valve replacement; CABG = coronary artery bypass graft surgery; LV = left ventricular; MV = mitral valve; TV = tricuspid valve.

Methods

Study patients. Intraoperative transesophageal echocardiography was performed in 143 patients undergoing mitral valve repair for mitral regurgitation between January 1, 1988 and November 30, 1990. The mean patient age was 61.5 ± 15.5 years (range 11 to 85). There were 87 men and 56 women (1.6:1). Twenty-eight patients underwent repair in 1988, 39 in 1989 and 76 in 1990.

The etiologies of mitral regurgitation as delineated by both two-dimensional transesophageal echocardiography and surgical exploration of the mitral valve are listed in Table 1. Sixty of the 100 patients with degenerative mitral valve disease had isolated prolapse of the posterior leaflet; 55 of these had a flail posterior leaflet segment. Thirty-six patients had bileaflet prolapse, including 17 with a flail posterior leaflet and 6 with a flail anterior leaflet. Four patients had anterior leaflet prolapse only, with a flail anterior leaflet segment present in three.

Of the 18 patients with mitral regurgitation due to ischemic heart disease, 2 had left ventricular aneurysm and another had rupture of a portion of the posteromedial papillary muscle in the presence of a very localized inferior myocardial infarction. The anterior leaflet was cleft in eight of the nine patients with mitral regurgitation caused by congenital cleft of the mitral valve. Rheumatic mitral valve disease without significant stenosis was responsible for mitral regurgitation in four patients. Miscellaneous causes of mitral regurgitation were treated infectious endocarditis (n = 4), severe aortic regurgitation with mitral annular dilation (n = 3) and dilated cardiomyopathy (n = 2); one patient each was operated on for mitral regurgitation complicating left atrial myxoma, penetrating chest trauma and previous failed mitral valve repair. No patient in this series had hypertrophic cardiomyopathy.

Cardiac operations (Table 2). Eighty-seven patients (61%) underwent mitral valve repair only (one patient with repeat repair). The remaining patients had mitral valve repair combined with one or more other procedures. The technique of repair varied according to pathologic findings and the discretion of the individual surgeon at the time of operation.

Intraoperative transesophageal echocardiography. Intraoperative transesophageal echocardiography was performed by utilizing the Hewlett-Packard 77020 or Sonos 1000 imaging system equipped with a 5-MHz transverse monoplane transducer-tipped endoscope. The probe was inserted with the patient in the supine position under general anesthesia; only rarely was direct laryngoscopic visualization required to pass the probe around the endotracheal tube. There were no complications from the intraoperative examination.

Detailed examination was performed by an experienced transesophageal echocardiologist utilizing basal short-axis, four-chamber and transgastric short-axis imaging planes as previously described (26), both before and after mitral valve repair. High resolution two-dimensional assessment of the functional morphology and leaflet malcoaptation of the mitral valve was obtained by using multiple four-chamber imaging planes, sweeping from the posterior to the anterior aspects of the valve. Segmental left ventricular function was evaluated by both four-chamber and transgastric short-axis imaging.

Mitral regurgitation was evaluated by Doppler color flow imaging, using multiple basal short-axis and four-chamber tomographic planes to map the full extent of the regurgitant jet by visual three-dimensional reconstruction. Eccentric mitral regurgitant jets were evaluated carefully with off-axis goal-directed imaging for the extent of wraparound along the circumference of the left atrium. Pulsed wave Doppler ultrasound of left and right upper pulmonary venous inflow was utilized to detect systolic flow reversal secondary to mitral regurgitation (27).

By composite Doppler analysis, mitral regurgitation was visually graded as 0 = absent—no detectable regurgitation; 0.5 = trivial—barely detectable regurgitation by Doppler color imaging; 1 = mild—narrow and localized regurgitant jet without eccentric trajectory or wraparound; 2 = moderate—regurgitant jet occupying approximately 25% to 33% of the left atrium without wraparound; 3 = moderate-severe—regurgitant jet occupying approximately 50% of the left atrium with some left atrial wraparound and systolic pulmonary venous flow reversal absent; and 4 = severe—regurgitant jet occupying >50% of the left atrium or with significant left atrial wraparound if eccentric and with systolic pulmonary venous flow reversal present.

Evaluation of mitral regurgitation was attempted as much as possible within a physiologic hemodynamic milieu in the

operative setting. Systematic pharmacologic manipulation of blood pressure to predetermined variables was not performed.

Postoperative transthoracic echocardiography. The trajectory and extent of the mitral regurgitant jet was evaluated by Doppler color flow mapping in several imaging planes and graded in severity as previously described (28). Continuous wave Doppler echocardiography was generally used to screen for an intense mitral regurgitant signal. Analysis of pulmonary venous inflow by pulsed wave Doppler echocardiography was performed in selected patients suspected of having significant residual mitral regurgitation.

Statistical analysis. Data are expressed as mean value ± SD. Comparison of the severity of mitral regurgitation before and after mitral valve repair was done by using the paired Student's *t* test. Analysis of etiologies of mitral regurgitation associated with unsuccessful initial mitral valve repair was performed using the Fisher exact test. Results were considered statistically significant at $p < 0.05$.

Results

Intraoperative transesophageal echocardiography before cardiopulmonary bypass. Before initiation of extracorporeal circulation, intraoperative transesophageal echocardiography demonstrated grade 4 mitral regurgitation in 117 patients (82%), grade 3 in 15 patients (11%), grade 2 in 9 patients (6%) and grade 1 in 2 patients (1%). The two patients with grade 1 mitral regurgitation had ischemic left ventricular dysfunction and grade 3 mitral regurgitation before general anesthesia but were evaluated during significant hypotension before cardiopulmonary bypass. The mean intraoperative transesophageal echocardiographic grade of mitral regurgitation was 3.6 ± 0.8 before mitral valve repair. At that time, the mean systolic blood pressure was 109 ± 12 mm Hg and mean pulmonary capillary wedge pressure (measured in 132 patients) was 17 ± 6 mm Hg.

Intraoperative transesophageal echocardiography after mitral valve repair. Intraoperative transesophageal echocardiography was repeated after cardiopulmonary bypass. Although we tried to evaluate the residual mitral regurgitation during physiologic hemodynamic conditions, it was not always possible because of moderate relative hypotension in some patients after cardiopulmonary bypass. The mean systolic blood pressure during postrepair evaluation of mitral regurgitation was 103 ± 11 mm Hg; mean pulmonary capillary wedge pressure was 14 ± 4 mm Hg.

After cessation of cardiopulmonary bypass, 126 patients (88.1%) were found to have excellent results from mitral valve repair, with grade ≤1 residual mitral regurgitation by intraoperative transesophageal echocardiography (Table 3). An example of successful mitral valve repair evaluated by two-dimensional and color Doppler transesophageal echocardiography is shown in Figure 1. Characteristic findings on pulsed wave Doppler ultrasound of pulmonary venous inflow before and after successful repair for severe mitral regurgitation are shown in Figure 2.

Table 3. Severity of Mitral Regurgitation by Intraoperative Transesophageal Echocardiography

MR Grade*	No. of Patients (%)	
	Before MV Repair	After MV Repair
0	0	38 (27)
0.5	0	58 (41)
1	2 (1)	30 (21)
2	9 (6)	5 (3)
3	15 (11)	9 (6)
4	117 (82)	3 (2)

*Mitral regurgitation (MR) grades: 0 = absent, 0.5 = trivial, 1 = mild 2 = moderate, 3 = moderate-severe, 4 = severe. MV = mitral valve.

Grade 2 residual mitral regurgitation was present in five patients; however, all patients had grade 4 regurgitation by intraoperative transesophageal echocardiography before cardiopulmonary bypass. Twelve patients had grade 3 to 4 residual mitral regurgitation after initial mitral repair and are discussed in detail later. There was significant improvement in the mean grade of mitral regurgitation in the entire group of patients with mitral repair (3.6 ± 0.8 to 0.7 ± 0.7; $p < 0.00001$).

Systolic anterior motion of the mitral valve. Thirteen patients (9.1%) had new severe systolic anterior motion of the mitral valve detected by intraoperative transesophageal echocardiography after mitral valve repair. The mitral valve disease present in this subset of patients before repair was bileaflet mitral valve prolapse in seven patients (five having a flail posterior leaflet segment), posterior mitral valve prolapse with flail segment in five and flail posterior leaflet secondary to partial papillary muscle rupture in one. Of these patients, 10 underwent wedge or quadrangular resection of a flail portion of the posterior mitral valve leaflet, with 1 patient also having anterior leaflet plication; 2 underwent bileaflet plication without resection and 1 had mitral ring annuloplasty only. Mitral ring annuloplasty was also performed in 12 of these patients; 10 had a flexible Duran annuloplasty ring (5 with a modified resection of a portion of the ring approximated to the anulus fibrosa) and 2 patients had a rigid Carpentier ring. Systolic anterior motion was also noted in one patient after a Kay suture annuloplasty.

Early in our experience, we believed that the appearance of systolic anterior motion in the early postcardiopulmonary bypass period after mitral valve repair was an indication for immediate revision of the repair or valve replacement (23). Hence, two patients, both having initial repair for bileaflet prolapse, underwent mitral valve replacement for severe systolic anterior motion and grade 4 residual mitral regurgitation. Three additional patients had further revision of the initial mitral valve repair for grade 3 residual mitral regurgitation associated with systolic anterior motion. No patient had residual systolic anterior motion or mitral regurgitation after the second repair procedure.

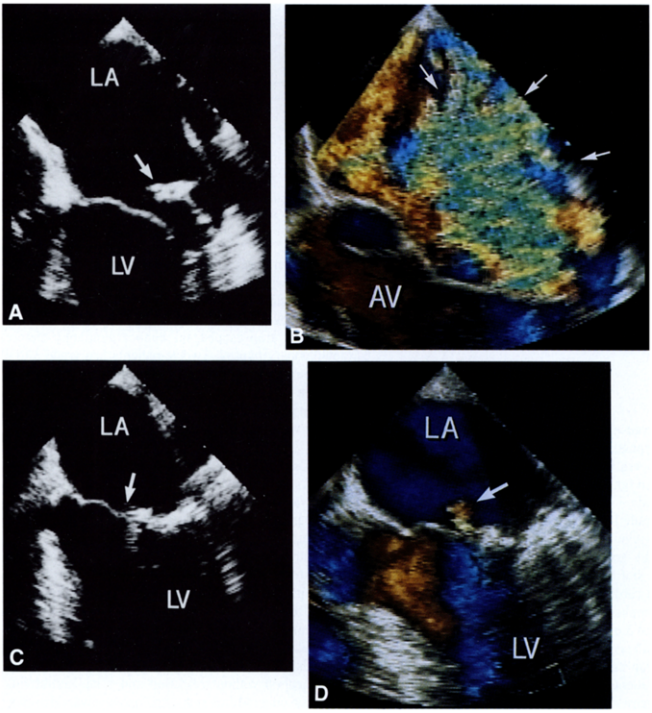


Figure 1. Intraoperative transesophageal echocardiography during mitral valve repair for treated infective endocarditis. **A**, Before mitral valve repair, the posterior mitral leaflet is flail with vegetations (**arrow**) and the anterior leaflet is normal. **B**, Severe central medial mitral regurgitation is detected by Doppler color flow mapping (**arrows**). **C**, After mitral valve repair, the flail portion of the posterior leaflet has been resected and coaptation of the anterior leaflet with the plicated posterior leaflet is intact (**arrow**). **D**, Trivial residual mitral regurgitation (**arrow**) is detected. AV = aortic valve; LA = left atrium; LV = left ventricle.

With further experience, we observed that postrepair systolic anterior motion was associated with a hyperdynamic hemodynamic state, generally precipitated by a combination of hypovolemia and intravenous catecholamine infusions. In our subsequent intraoperative studies, eight patients (5.6% of the entire series)—five with grade 2 and three with grade 3 mitral regurgitation—were found to have transient systolic anterior motion responsible for the initial degree of postrepair mitral regurgitation. With intravascular volume repletion and reduction or cessation of intravenous inotropic therapy, all eight patients had near or complete resolution of systolic anterior motion without further surgical intervention. All eight patients had grade ≤1 residual mitral regurgitation before leaving the operating room. The transesophageal echocardiographic findings in one patient with transient systolic anterior motion after initial mitral valve repair are shown in Figure 3.

Other mechanisms of significant mitral regurgitation after initial repair. Aside from the patients with postcardiopulmonary bypass systolic anterior motion just discussed, six

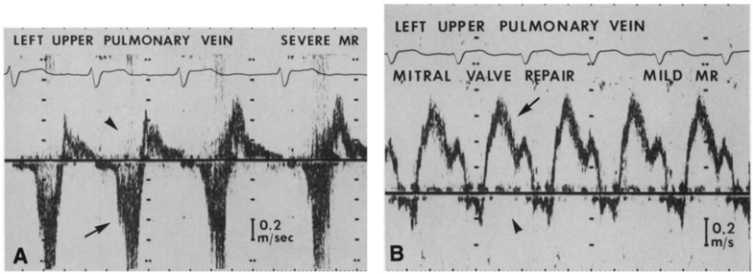


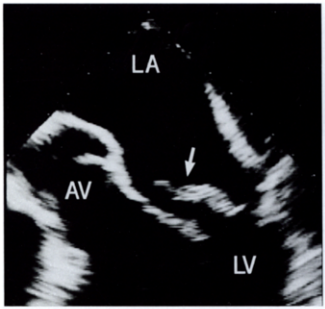
Figure 2. Intraoperative transesophageal pulsed wave Doppler echocardiography of the left upper pulmonary vein during mitral valve repair for severe mitral regurgitation (MR). A, before mitral valve repair, turbulent pulmonary venous systolic flow reversal secondary to severe mitral regurgitation is present (arrow) and normal anterograde systolic flow is absent (arrowhead). B, After mitral valve repair, normal laminar anterograde pulmonary venous inflow is detected (arrow) in the presence of mild residual mitral regurgitation. Turbulent systolic flow reversal is now absent (arrowhead).

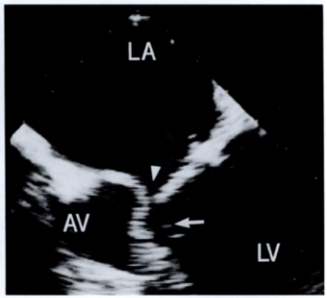
patients (4.2% of the entire series) had moderate to severe residual mitral regurgitation after initial mitral valve repair because of other causes. Residual anterior mitral prolapse or flail leaflet segment was the responsible mechanism in four patients. Persistent anterior mitral leaflet restriction of coaptation due to rheumatic disease was present in one patient. Another patient had residual posterior prolapse in combination with excessive anterior leaflet plication, causing significant residual mitral regurgitation.

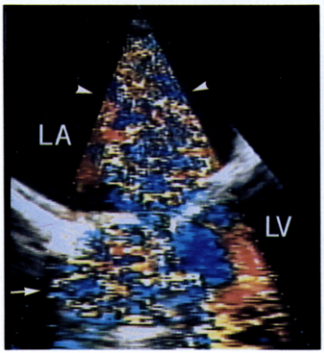
Operative intervention for significant residual mitral regurgitation. The operative interventions for grade 3 to 4 residual mitral regurgitation after initial mitral repair are summarized in Table 4. A total of five patients (3.5%) underwent mitral valve replacement after the initial mitral repair was judged to be unsuccessful. Revision of the initial repair was performed in another five patients (3.5%). Three patients had additional posterior leaflet plication for systolic anterior motion, one had additional anterior plication for residual flail segment and one had both additional posterior plication for posterior prolapse and partial release of excessive anterior leaflet plication that initially caused posterior leaflet override. All patients with revised mitral repair had grade ≤1 residual mitral regurgitation by intraoperative transesophageal echocardiography after the second repair procedure. An example of a patient with initially inadequate and then successfully revised mitral valve repair is shown in Figure 4. The remaining patient had grade 3 residual mitral regurgitation secondary to residual anterior mitral prolapse. Because of severe left ventricular dysfunction and marginal hemodynamics, the surgeon decided that a second period of cardiopulmonary bypass was of prohibitive risk and no further operative intervention was pursued. This patient eventually left the hospital in stable condition.

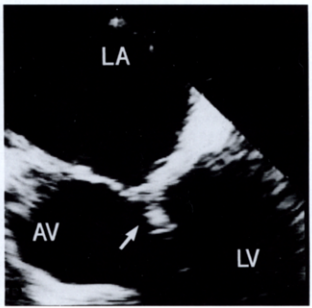
By the Fisher exact test, the degree of statistical association of underlying mitral valve disease with grade 3 to 4 residual mitral regurgitation after initial repair is shown in Table 5. Mitral valve prolapse involving both leaflets (seven patients) or just the anterior leaflet (two patients) with or without flail was present in 82% of all patients undergoing a second operative procedure after the initial mitral valve repair. The presence of bileaflet prolapse or anterior leaflet prolapse was statistically associated with the risk of unsuccessful initial repair, considering only the 100 patients with prolapse or flail segment or the entire 143-patient study group. Prolapse of the posterior leaflet only (with or without flail segment) was not associated with risk of further immediate operative intervention. One (1.7%) of 60 patients with isolated posterior leaflet disease had unsuccessful initial repair compared with 9 (22.5%) of 40 patients with bileaflet or isolated anterior leaflet myxomatous disease. No other etiology of mitral regurgitation was statistically associated with significant residual mitral regurgitation after mitral valve repair (Table 5); however, the numbers of patients in these subgroups were relatively small.

Adjunctive impact of intraoperative transesophageal echocardiography. In addition to the evaluation of mitral valve repair, intraoperative transesophageal echocardiography was useful in the delineation of other lesions unsuspected before operation, prompting additional surgical intervention in four patients (2.8%) in this series. Two patients were found to have small secundum atrial septal defects, which were repaired. One patient was shown to have a flail septal tricuspid valve leaflet secondary to papillary muscle rupture after decannulation of the right heart chambers; the tricuspid valve was successfully repaired (29). A small aorto-left atrial shunt after previous aortic valve replacement was found in another patient and was repaired at the time of mitral repair.









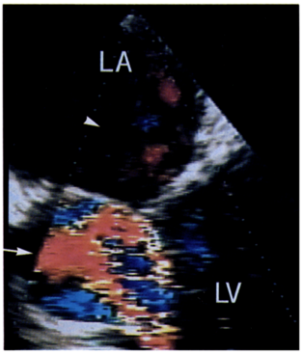


Figure 3. Transient systolic anterior motion of the mitral valve after repair performed because of severe mitral regurgitation due to a flail posterior leaflet. **A,** Before valve repair, the posterior mitral leaflet is flail (**arrow**) and the anterior leaflet is anatomically normal. **B,** Immediately after repair and cessation of cardiopulmonary bypass, severe systolic anterior motion of the anterior mitral leaflet (**arrow**) causes incomplete coaptation (**arrowhead**) with the plicated posterior leaflet. At this time, the patient was hypovolemic and receiving intravenous dopamine. **C,** Doppler color flow mapping demonstrates significant residual mitral regurgitation (**arrowheads**) with a posterolateral trajectory perpendicular to the left ventricular outflow tract and turbulent flow in this tract (**arrow**) due to obstruction; both findings were precipitated by systolic anterior motion. **D,** After intravascular volume repletion and cessation of inotropic therapy, systolic anterior motion has resolved and mitral leaflet coaptation is intact (**arrow**). **E,** Doppler color flow mapping reveals no residual mitral regurgitation (**arrowhead**) and laminar flow signals within the left ventricular outflow tract (**arrow**) in the absence of obstruction. Revision of the mitral valve repair was not necessary. AV = aortic valve; LA = left atrium; LV = left ventricle.

Table 4. Intervention in 11 Patients With Grade 3 to 4 Residual Mitral Regurgitation After Initial Mitral Valve Repair

	No. of Patients
MV replacement	
Systolic anterior motion	2
Residual anterior MV prolapse or flail	2
Rheumatic anterior MV leaflet restriction	1
Revision of initial MV repair	
Systolic anterior motion	3
Residual anterior MV leaflet flail	1
Residual posterior MV prolapse, excessive anterior MV leaflet plication	1
Observation only	
Residual anterior MV prolapse, severe LV dysfunction	1

LV = left ventricular; MV = mitral valve.

Predischarge transthoracic echocardiography. Transthoracic two-dimensional and Doppler echocardiography was performed in 140 patients (98%) before postoperative hospital discharge. One patient died on the 2nd postoperative day (total in-hospital hospital mortality rate 0.7%) and was not studied. Two additional patients were discharged without follow-up study. Transthoracic Doppler assessment of mitral regurgitation was inadequate for analysis in three patients (2.1%); none of these patients underwent transesophageal echocardiography. Four of the five patients with a mitral prosthesis had a normal transthoracic examination of the prosthesis; the fifth patient had mild periprosthetic regurgitation that was also detected by intraoperative transesophageal echocardiography.

Excellent results of mitral valve repair with grade ≤1 residual mitral regurgitation by composite Doppler examination were present in 114 (86.4%) of the remaining 132 patients (Table 6). Fifteen patients had grade 2 residual mitral regurgitation and three patients had grade 3 mitral regurgitation; all but one patient had grade 4 mitral regurgitation by transthoracic Doppler examination preoperatively.

No patient had significant systolic anterior motion of the mitral apparatus or left ventricular outflow tract obstruction evident by continuous wave Doppler echocardiography.

The mean grade of mitral regurgitation by transthoracic Doppler echocardiography (0.8 ± 0.7) was slightly greater than that observed by intraoperative transesophageal echocardiography after mitral repair (0.7 ± 0.7) and was of borderline statistical significance $p < 0.05$). Systolic blood pressure during the transthoracic Doppler evaluation was also higher than during intraoperative transesophageal echocardiography after mitral repair (127 ± 14 vs. 103 ± 11 mm Hg; $p < 0.00001$).

A significant discrepancy (> 1 grade) between the grade of mitral regurgitation by intraoperative transesophegeal echocardiography after mitral valve repair and by transthoracic Doppler echocardiography before hospital discharge was observed in 17 patients (12.9%). In 16 (94%) of these 17 patients, the grade of residual mitral regurgitation was higher on the predischarge transthoracic study than on the intraoperative transesophageal echocardiography (2.1 ± 0.6 vs. 0.9 ± 0.8; $p < 0.0001$). Systolic blood pressure during intraoperative transesophageal echocardiographic assessment was significantly lower in this subset of patients (93 ± 10 vs. 131 ± 21 mm Hg; $p < 0.00001$), with 10 patients having a systolic blood pressure ≤90 mm Hg.

Discussion

Because of the many potential advantages of mitral valve reconstruction over prosthetic valve replacement (1,3–5,7–13), mitral valve repair remains the procedure of choice at our institution for the surgical therapy of severe mitral regurgitation. Currently, experienced surgeons are applying more aggressive repair techniques to less favorable mitral valvular anatomy. Hence, intraoperative knowledge of the results of repair is becoming increasingly important.

Transesophageal versus epicardial intraoperative echocardiography. Although epicardial Doppler color flow mapping has been shown to be a very effective means of assessing mitral regurgitation intraoperatively (21–23,30), we prefer the use of transesophageal imaging for several reasons. The transesophageal approach does not interrupt the operation and can be readily performed by one echocardiologist who is not intruding into the sterile field. Unimpeded high frequency near- to mid-field images of the mitral apparatus and mitral regurgitant jet are possible by transesophageal imaging (31,32), whereas farther field epicardial windows may be obscured by acoustic shadowing from aortic or mitral valve disease or even motion artifact from on-heart transducer placement.

Transesophageal imaging planes may be limited in the four-chamber format (33), especially in patients with vertical orientation of the heart within the chest. Careful short-axis imaging of the regurgitant jet, supplemented by pulsed wave Doppler analysis of pulmonary venous inflow (not readily accessible by the epicardial approach), generally permits adequate assessment of mitral regurgitation. Recently available (34,35) biplane transesophageal imaging systems will further enhance both two-dimensional imaging of the mitral apparatus and semiquantitation of mitral regurgitation by Doppler color flow mapping and provide additional windows for Doppler evaluation of pulmonary venous inflow.

Evaluation of mitral regurgitation by intraoperative transesophageal echocardiography. Evaluation of mitral regurgitation by Doppler color transesophageal echocardiography has been found to correlate with results of contrast left ventriculography, especially at the extremes of severity (32). The assessment of residual mitral regurgitation after mitral repair by intraoperative transesophageal echocardiography has also been shown to correlate well with the severity of mitral regurgitation by contrast left ventriculography in the early postoperative period (25).

In patients with adequate repair assessed by intraoperative transesophageal echocardiography, there was good

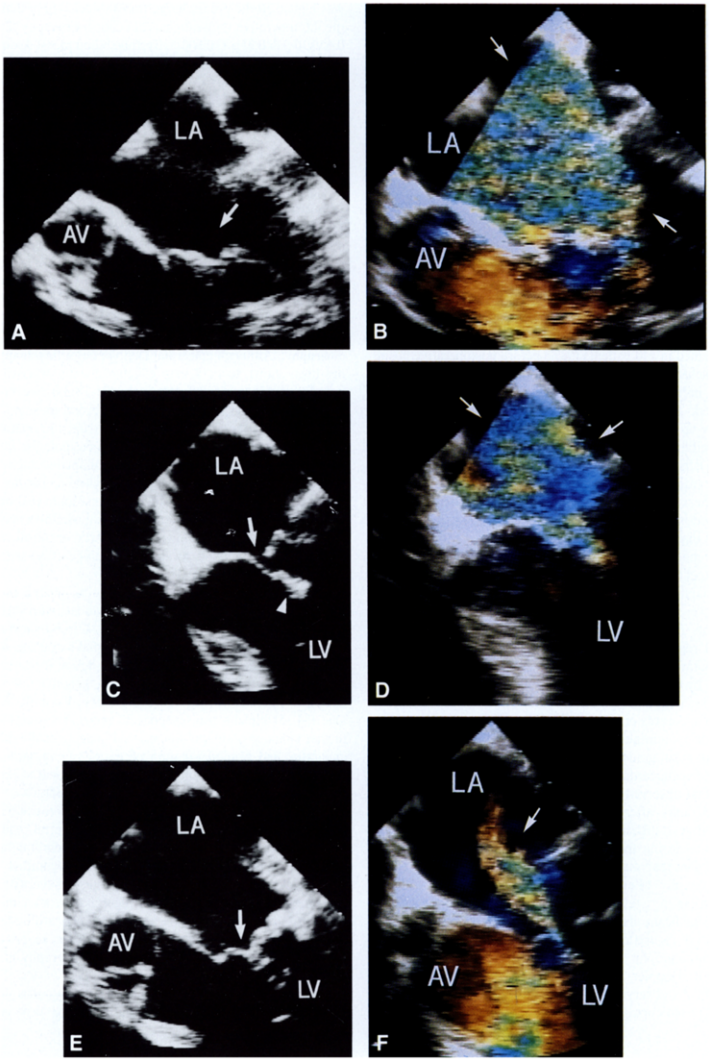

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Figure 4 (opposite page). Intraoperative transesophageal echocardiography of bileaflet repair for mitral valve prolapse. A, Before mitral valve repair, bileaflet mitral valve prolapse is present (arrow) without flail leaflet segment. B, Severe central mitral regurgitation (arrows) is demonstrated by Doppler color flow mapping. C, After initial mitral valve repair, excessive plication of the anterior leaflet (arrowhead) results in override of the plicated posterior leaflet and malcoaptation (arrow) of the leaflets. D, Significant residual mitral regurgitation (arrows) is shown by Doppler color flow mapping, with an anteromedial trajectory with left atrial wraparound. E, After revised mitral valve repair, revision of the anterior leaflet plication now allows intact coaptation (arrow). F, Mild central mitral regurgitation is detected by Doppler color flow mapping (arrows). AV = aortic valve; LA = left atrium; LV = left ventricle.

agreement with the predischarge transthoracic Doppler echocardiographic assessment of residual mitral regurgitation by ≤1 grade in 88% of patients. The relatively unimpeded high resolution Doppler color flow images obtainable by the transesophageal window could potentially lead to overestimation of the severity of mitral regurgitation compared with results of transthoracic examination (36). However, in those patients with discordant results of postrepair intraoperative transesophageal echocardiography and predischarge transthoracic echocardiography, the residual mitral regurgitation was consistently underestimated by the transesophageal approach. This is probably due to hemodynamic conditions reflective of significantly lower left ventricular afterload during intraoperative evaluation.

Incidence and implications of systolic anterior motion. New systolic anterior motion of the mitral valve was detected by intraoperative transesophageal echocardiography in 9.1% of all patients in this study immediately after mitral valve reconstruction. The majority of patients underwent mitral ring annuloplasty placement, but in 83% the ring was flexible, unlike the rigid Carpentier ring previously associated with postrepair systolic anterior motion (37–39). One patient with only a suture (Kay) annuloplasty also had significant postbypass systolic anterior motion.

Importantly, we observed that systolic anterior motion accompanied by significant mitral regurgitation resolved without further surgical intervention in those patients observed with correction of the postcardiopulmonary bypass hyperdynamic state (typically caused by hypovolemia and intravenous catecholamine infusions). Residual mitral regurgitation assessed by intraoperative transesophageal echocardiography likewise significantly diminished in these patients, and revision of repair or valve replacement was not necessary. In contrast to findings in previous reports (37–39), no patient in this series had left ventricular outflow tract obstruction or mitral regurgitation induced by systolic anterior motion on predischarge transthoracic echocardiography.

Table 5. Mitral Valve in Patients Having Further Operative Intervention for Grade 3 or 4 Mitral Regurgitation After Initial Mitral Repair

	No. of Patients	p Value (Fisher exact test)	
		Patients With MV Prolapse (n = 100)	All Patients With MV Repair (n = 143)
Bileaflet MV prolapse ± flail	36	0.010	0.009
Anterior MV prolapse ± flail	4	0.005	0.004
Posterior MV prolapse ± flail	60	NS	NS
Ischemic LV dysfunction	18	NS	NS
Rheumatic MV disease	4	NS	NS
Cleft MV leaflet	9	NS	NS

LV = left ventricle; MV = mitral valve; ± = with or without.

Table 6. Predischarge Transthoracic Doppler Echocardiography After Mitral Valve Repair

Residual MR Grade*	No. of Patients (%)
0	25 (19)
0.5	53 (40)
1	36 (27)
2	15 (11)
3	3 (2)
4	0

*Mitral regurgitation (MR) grades: 0 = absent; 0.5 = trivial; 1 = mild; 2 = moderate; 3 = moderate to severe; 4 = severe.

Impact of intraoperative echocardiography. Intraoperative transesophageal echocardiography aided in the identification of significant (grade >2) residual mitral regurgitation in 11 patients (7.7%) in this study, prompting revision of the initial repair or prosthetic valve replacement in all but 1 before the patient left the operating room. Before we recognized the potential reversibility of postcardiopulmonary bypass systolic anterior motion, five patients (3.5%) underwent a second procedure for mitral regurgitation caused by this mechanism. It is unknown if further postbypass observation and hemodynamic intervention would have resulted in reduction in systolic anterior motion or residual mitral regurgitation in these five patients. Other etiologies of mitral malcoaptation, such as residual prolapse, flail segment or restriction of leaflet motion, were delineated by transesophageal echocardiography in the remaining six patients (4.2%). These results are similar to the 8% overall incidence of inadequate mitral valve repair reported by Stewart et al. (23) utilizing intraoperative epicardial echocardiography; three patients (3% of their series) having a second surgical procedure had systolic anterior motion with dynamic left ventricular outflow tract obstruction. By employing intraoperative contrast transesophageal echocardiography, Dahm et al. (19) detected severe residual mitral regurgitation in 16% of a small group of patients after mitral valve repair; the incidence of systolic anterior motion was not reported in that study.

Two-dimensional echocardiographic imaging is the only effective intraoperative means of delineating the functional morphology of the mitral valve in the contracting heart. Even if significant residual mitral regurgitation is detected by

any intraoperative technique, it may be the mechanism of mitral leaflet malcoaptation demonstrated by intraoperative echocardiography, which will arbitrate the need for further operative intervention.

It is now our practice to closely observe the response of systolic anterior motion to volume repletion and cessation of catecholamine infusion in the immediate postcardiopulmonary bypass period. Only if significant systolic anterior motion and mitral regurgitation persist after resolution of the hyperdynamic state would reexploration of the mitral valve be considered. Further revision of the repair or even replacement is indicated for other defects in mitral coaptation, such as residual flail segment, prolapse with leaflet override or restriction of leaflet excursion secondary to excessive mitral plication or rheumatic disease.

Intraoperative transesophageal echocardiography also has an ancillary impact with the discovery of other cardiac disease at the time of mitral valve surgery. In our study, four patients (2.8%) were found to have unsuspected lesions that prompted surgical attention. Significant additional valvular or congenital defects warranting surgical intervention were observed by Sheikh et al. (24) in up to 11% of patients undergoing mitral valve procedures.

Limitations. As with the evaluation of mitral regurgitation by either transthoracic or transesophageal echocardiography in the nonoperative setting, Doppler color flow mapping by intraoperative transesophageal echocardiography can be influenced by multiple technical and physiologic aspects. Delineation of the mitral regurgitant jet is affected by the instrument used, gain settings and available windows. The mitral regurgitant volume and orifice, driving left ventricular systolic pressure, left atrial pressure and compliance, as well as the mechanism of leaflet malcoaptation, all affect the configuration and trajectory of the mitral regurgitant jet defined by Doppler color flow mapping. Eccentric mitral regurgitant jets, typically seen with mitral prolapse or flail leaflet segments, or both, adhere to the wall of the left atrium because of the Coanda effect, decreasing the apparent size of the regurgitant signal by Doppler color echocardiography (40,41). Careful delineation of such eccentric jets in multiple imaging planes in search of regurgitant jet wraparound along the circumference of the left atrium is mandatory. Pulsed wave Doppler echocardiography of pulmonary venous inflow, with pulmonary venous systolic flow reversal being a highly sensitive finding for severe mitral regurgitation (27), provides complementary information and should be routinely performed. The finding of regurgitant jet left atrial wraparound is probably more meaningful than the results of quantitating jet surface areas and ratios for assessing eccentric mitral regurgitation; however, further investigation is needed.

The evaluation of mitral regurgitation by intraoperative transesophageal echocardiography is also confounded by the labile hemodynamic milieu of the operating room. The multiple effects of general anesthesia are inescapable and the influence of fluctuating intravascular volume status, inotropic and vasodilator therapy on both mitral valve leaflet coaptation and resultant mitral regurgitation can be significant. Intraoperative reduction in left ventricular afterload was likely responsible for the discordant underestimation of residual mitral regurgitation by intraoperative transesophageal versus predischarge transthoracic echocardiography in nearly 13% of patients in this study. Nevertheless, transthoracic Doppler echocardiographic evaluation of residual mitral regurgitation was in agreement with intraoperative transesophageal echocardiography by ≤1 grade in nearly 90% of patients in this study. Only three patients (2.1%) were found to have grade ≥2 residual mitral regurgitation on predischarge transthoracic Doppler echocardiography who were thought to have insignificant mitral regurgitation during intraoperative transesophageal echocardiography.

Conclusions. Two-dimensional and Doppler transesophageal echocardiography is valuable in the intraoperative assessment of mitral valve repair. This technique allows detailed definition of the functional morphology of the mitral leaflets, anulus and support apparatus before and after repair with semiquantitation of residual mitral regurgitation, providing important immediate feedback to the surgeon. There is a complex interplay between the dynamics of mitral regurgitation and the labile intraoperative hemodynamic environment. Transient systolic anterior motion of the mitral apparatus causing significant postrepair mitral regurgitation is not uncommon immediately after mitral valve repair. This phenomenon appears to be precipitated by a hyperdynamic state caused by postcardiopulmonary bypass hypovolemia in combination with catecholamine infusion. The potential pitfalls of color Doppler technology in the intraoperative setting must be acknowledged, and evaluation by an experienced transesophageal echocardiographer is essential.

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