Journal of the American Society of Echocardiography
Volume 15 • Number 9 • September 2002

Intraoperative transesophageal echocardiography accurately predicts mitral valve anatomy and suitability for repair

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0894-7317/2002/$35.00 + 0 **27/1/121534**

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Mitral valve (MV) repair is the procedure of choice for MV prolapse or flail. However, valve repair is more technically demanding and requires a precise definition of MV morphology to determine the timing, complexity, and feasibility of repair. We prospectively examined 170 consecutive patients with MV prolapse or flail referred for MV repair. The MV valve was systematically assessed by intraoperative transesophageal echocardiography. MV anatomy was independently assessed at the time of operation. Accuracy of transesophageal echocardiography in identifying MV segments ranged from 90% to 97%, and was best for the middle segment/scallop of either anterior or posterior leaflet. MV repair was successful in 91% of patients. Success rate was the lowest (78%) in the presence of extensive bileaflet disease involving at least 2 segments of each leaflet. Independent predictors of unsuccessful repair were central jet of mitral regurgitation, calcification or severe dilatation of the mitral annulus, and extensive leaflet disease with involvement of at least 3 segments. (J Am Soc Echocardiogr 2002;15:950-7.)

Myxomatous degeneration with resultant leaflet prolapse is a common cause of isolated mitral regurgitation in adults.[1] Moderate or severe mitral regurgitation in the setting of myxomatous disease is usually the result of either severe leaflet prolapse or a flail segment. Recent studies have suggested that early operation improves survival in patients with severe mitral regurgitation from mitral valve (MV) prolapse.[2] [3] Recently published practice guidelines have suggested that asymptomatic patients with significant mitral regurgitation should undergo operation if MV repair is feasible. [4] As MV repair has superior clinical outcomes but is more technically challenging in comparison with valve replacement, [5] [7] the precise definition of MV morphology is crucial in determining the feasibility, timing, and complexity of repair.

Multiplane transesophageal echocardiography (TEE) allows imaging in numerous scan planes, which can be optimally aligned to specific anatomic orientations to provide detailed information.[8] [9] Although TEE provides important insights into the mechanism of mitral regurgitation and is crucial in the immediate postoperative assessment of MV repair,[9] [11] its use in predicting the feasibility of MV repair has not been well defined. Although several recent studies have proposed several methods to systematically define the morphology of the MV, their imaging algorithms were developed from a retrospective review of images obtained in patients with predominant posterior MV leaflet involvement.[12] [15] In several of these algorithms, there was overlapping of different segments within the same views.[12] [14] Because patients had a variety of valvular diseases in these previous studies,[12] [14] it is difficult to generalize their results to the TEE evaluation of myxomatous MV disease that is amenable to repair even in the presence of extensive disease.[16] The purpose of this study was to prospectively determine the accuracy of a systematic approach to the identification of a flail or prolapsed segment in a large consecutive series of patients referred to a single surgical group with established expertise in MV repair. We also identified predictors of unsuccessful repair and developed a clinical prediction rule.

Methods

We prospectively examined consecutive patients with MV prolapse referred to the Toronto General Hospital for MV repair during the period November 1996 to December 1999. Intraoperative TEE examination was performed in all patients using a 5-MHz multiplane transducer and echocardiograph (2500 Sonos, Agilent, Andover, Mass). TEE was performed after anesthetic induction and before initiation of cardiopulmonary bypass. Echocardiographic data were collected prospectively. The segments of the MV similar to that defined by Carpentier et al[17] were identified by systematic rotation of the scan plane from the positioning of the TEE transducer in the midesophagaus (Figure 1).

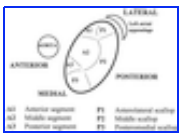

Fig. 1. Schematic drawing of Carpentier et al[17] approach to segmental valve analysis. Posterior mitral valve leaflet is divided into 3 scallops, typically with large middle scallop. Anterior mitral valve leaflet is divided into 3 corresponding segments.

The anterior leaflet was divided into anterior, middle (A2), and posterior segments; the posterior leaflet was divided into anterolateral (P1), middle (P2), and posteromedial (P3) scallops. This systematic approach was modified from that reported by Foster et al[12] (Figure 2).

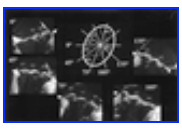

Fig. 2. Display of segmental approach to visualization of mitral valve morphology by transesophageal echocardiography used in current study. Anterior, middle, and posterior segment of anterior leaflet denoted by *A1*, *A2*, and *A3*, respectively. Anterolateral, middle, and posterolateral scallop of posterior leaflet denoted by *P1*, *P2*, and *P3*, respectively. Views were obtained in 5 standard planes. Beginning at 0 degrees, beam is aligned to middle segments. As probe is steered through arc of 180 degrees, more medial and then more lateral segments are visualized. *Arrows* mark level of annular plane. Patient has extensive bileaflet disease with prolapse of all segments/scallops except for A1.

However, in contrast to the approach reported by Foster et al,[12] the TEE transducer was maintained in a neutral rotation with neither anteflexion nor retroflexion during the rotation of the scan plane. The number of prolapsed or flail segments were identified on line by an experienced echocardiographer (A.S.O.). The end-diastolic medial-lateral mitral annular diameter was measured from the apical 4- chamber view (0-degree rotation). The presence or absence of mitral annular calcification was also noted. The severity of mitral regurgitation was assessed from the maximal regurgitant jet area and pulmonary venous Doppler sampling. Mitral regurgitation was classified as follows: trivial, color jet area less than 2.0 cm^2 ; mild, color jet area 2.0 to 3.9 cm^2 ; moderate, color jet area 4.0 to 8.0 cm^2 ; and severe, color jet area more than 8.0 cm^2 with pulmonary venous systolic blunting of 50% or more, or flow reversal.[18] [20] The direction of the mitral regurgitant jet was characterized as either anterior, posterior, central, or multiple. Left ventricular (LV) systolic function was visually assessed as either normal (ejection fraction ≥ 60%), mildly reduced (ejection fraction 40% to 59%), moderately reduced (ejection fraction 20% to 39%), or severely reduced (ejection fraction < 20%). [21]

The identity and number of prolapsed or flail MV segments/scallops were independently assessed by the cardiac surgeon before attempted repair (T.E.D. or C.M.F.). After MV repair, a second TEE was performed to document the extent of residual mitral regurgitation, MV area, and LV systolic function. Before hospital discharge, another transthoracic echocardiogram was performed to assess residual mitral regurgitation and LV systolic function. Perioperative (30-day) mortality was also determined. This study was approved by the Research Ethics Board of the University Health Network.

Data analysis

Continuous data were displayed as mean + SD. TEE identification of scallops/segments was compared with surgical findings (standard of comparison) and expressed as sensitivity, specificity, and accuracy (concordance between TEE and surgical inspection for both diseased and normal scallops/segments). The univariate analysis of the predictors of MV replacement (unsuccessful MV repair) was performed using chi-square, Fisher exact, or Student *t* tests wherever appropriate. Potential predictors include age, sex, preoperative New York Heart Association functional class and LV systolic function, site and extent of prolapsed or flail MV segments on TEE and at operation, annular diameter or calcification on TEE, direction of mitral regurgitant jet, and nature of MV repair. Univariate predictors with a level of significance ≤.10 were entered into a backward stepwise multivariate logistic regression analysis (level of significance <.05 for entry into the model); correlated variables were combined. The results of the logistic regression model were cross-validated on the total patient group using bootstrap method (using the entire sample of 170 patients and 1000 iterations).[22] Independent predictors of unsuccessful MV repair were incorporated into a point score.

Results

One hundred and seventy consecutive patients with MV prolapse underwent MV operation during the study period. Their mean age was 60 ± 13 years (range 23 to 84 years); 30% of the patient group was female. Eighty-eight patients (52%) had symptoms of pulmonary congestion before MV repair. Twenty-six patients (15%) had a history of atrial fibrillation. The preoperative LV systolic function was normal in 87% of patients; the remainder had mild (11%) or moderate (2%) LV systolic dysfunction. On the preoperative TEE study, 94% of patients had severe mitral regurgitation; the remainder had moderate mitral regurgitation. The accuracy of TEE identification of the various segments/scallops ranged from 90% to 97% (Table 1).

Table 1. Transesophageal echocardiographic assessment of mitral valve segments compared with surgical findings

Segment	Sensitivity (%)	Specificity (%)	Accuracy* (%)
Anterior leaflet segment			

Anterior	5/9 (56%)	156/161 (97%)	161/170 (95%)
Middle	109/111 (98%)	50/59 (85%)	159/170 (94%)
Posterior	53/65 (82%)	100/105 (95%)	153/170 (90%)
Posterior leaflet scallop			
Anterolateral	10/12 (83%)	146/158 (92%)	156/170 (92%)
Middle	149/150 (99%)	15/20 (75%)	164/170 (97%)
Posteromedial	80/91 (88%)	75/79 (95%)	155/170 (91%)
Any anterior segment	115/117 (98%)	47/53 (89%)	162/170 (95%)
Any posterior scallop	161/161 (100%)	9/9 (100%)	170/170 (100%)
Scallop/segment on both leaflets	106/108 (98%)	56/62 (90%)	162/170 (95%)
*			

* Refers to concordance between transesophageal echocardiographic and surgical assessment that the segment in question is abnormal or normal

TEE was the most accurate (97%) in identifying P2. TEE was the least accurate in identifying the posterior segment of the anterior leaflet (90%). The accuracy of TEE in localizing to the anterior and posterior leaflets was 95% and 100%, respectively. Mitral regurgitant jet direction is displayed in Figure 3.

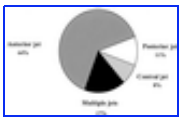

Fig. 3. Proportion of patients with various mitral regurgitant jet direction.

The most common direction of the mitral regurgitant jet is anterior in location, reflecting posterior leaflet involvement in a large proportion of patients.

At the time of operation, the most common segment of prolapse or flail was P2 or A2 (Figure 4).

Fig. 4. Graph illustrates disease involvement for individual valve segments as identified on transesophageal echocardiogram (*TEE*) and direct surgical inspection (*OR*). Anterior, middle, and posterior segment of anterior leaflet denoted by *A1*, *A2*, and *A3*, respectively. Anterolateral, middle, and posterolateral scallops of posterior leaflet denoted by *P1*, *P2*, and *P3*, respectively. Middle segment or scallop of both leaflets was most commonly involved.

The least common segment involved was the anterior segment of the anterior leaflet. The operative techniques used for MV repair are shown in Figure 5.

Fig. 5. Type of operative techniques used in mitral valve repair (not mutually exclusive). Majority of patients required insertion of mitral annuloplasty ring (*Ring*) and quadrangular resection (*Quad*) of prolapsed portion and sliding plasty (*S. Plasty*). Fifty-eight percent of patients required the insertion of artificial chordae (*Chordae*).

All patients had mitral annuloplasty with a ring or band of polyethylene terephthalate fabric. The majority of patients (73%) required the insertion of an annuloplasty ring, quadrangular resection of the posterior leaflet,

and a sliding plasty. In 59% of patients, replacement with artificial chordae (99 patients) or chordae transfer (1 patient) was performed. One or more additional surgical procedures (coronary artery bypass operation, 12 patients; maze procedure, 13 patients; aortic valve replacement, 7 patients; tricuspid valve repair, 5 patients; and closure of patent foramen ovale, 5 patients) were performed in 36 patients (21%).

MV repair was successful in 91% of the patients. Sixteen patients (9%) underwent MV replacement because of a persistent unacceptable degree of mitral regurgitation shown on TEE after an attempt at repair. A successful postoperative TEE result was defined as no more than mild mitral regurgitation on the immediate postrepair TEE. Six patients required a second pump run for revision of the repair; 1 of the 6 patients required MV replacement. The success of repair in relationship to the number of anterior and posterior segments as predicted by TEE are demonstrated in Table 2.

Table 2. Transesophageal echocardiographic assessment of site and extent of mitral valve prolapse or flail and success rate of valve repair*

Number of posterior scallops	**Number of anterior segments**		
	0	**1**	**≥ 2**
0		6/7 = 86% (42%-100%)	2/2 = 100% (16%-100%)
1	33/33 = 100% (89%-100%)	31/32 = 97% (84%-100%)	12/12 = 100% (74%-100%)
≥2	15/16 = 94% (70%-100%)	20/23 = 87% (66%-97%)	35/45 = 78% (63%-89%)

* 95% confidence limits for success rates are in parentheses.

Success was highest in patients with posterior leaflet disease involving only 1 scallop regardless of the number of anterior segments involved. Success was lowest in the presence of extensive bileaflet disease involving at least 2 segments/scallops of each leaflet.

Patients with bileaflet disease involving at least 2 segments/scallops of each leaflet represented 12 of the 16 unsuccessful repairs; TEE correctly identified the extent of disease in 10 of these 12 patients. In the other 4 patients with unsuccessful repair, there was bilateral leaflet disease in 2 patients (A3P2P3 in 1 patient and A2P2 in the other); only 1 leaflet was involved in each of the other 2 patients (isolated A2 in 1 and P2P3 of the posterior leaflet in the other).

The role of clinical, echocardiographic, and surgical factors in predicting the need for MV replacement was examined by univariate and multivariate analysis (Table 3).

Table 3. Predictors of need for mitral valve replacement

			P	
Predictor	**Successful repair (%)**	**Mitral valve replacement (%)**	**Univariate**	**Multivariate**
N	154	16		
Age ≥ 60 years	84 (55%)	10 (63%)	.54	—
Female	47 (70%)	4 (25%)	.44	—

Baseline NYHA 3-4	65 (42%)	10 (63%)	.12	—
TEE findings				
Anterior MR jet	105 (68%)	5 (31%)	.003	—
Posterior MR jet	18 (12%)	0	.22	—
Central MR jet	7 (5%)	6 (38%)	<.001	.0017
Multiple MR jets	24 (16%)	5 (31%)	.11	—
Annular dil/Ca	25 (16%)	6 (38%)	.036	.034
Preoperative LVEF < .40	3 (2%)	2 (13%)	.07	—
Prolapse of any Ant seg	106 (69%)	15 (94%)	.042	—
Prolapse of any Post scal	146 (95%)	15 (94%)	.60	—
Prolapse of any segment or scallop on both leaflets	98 (64%)	14 (88%)	.093	—
Prolapse > 1 Ant seg	49 (31%)	10 (63%)	.024	—
Prolapse > 1 Post scal	70 (45%)	14 (88%)	.001	—
Prolapse >1 segments/scallop on both leaflets	70 (45%)	14 (88%)	.001	—
Prolapse ≥ 3 segments/scal	67 (43%)	14 (88%)	.001	.013
Surgical findings and procedure				
Prolapse of any Ant seg	102 (66%)	15 (94%)	.023	—
Prolapse of any Post scal	146 (95%)	15 (94%)	.60	—
Prolapse of any segment/scal on both leaflets	94 (61%)	14 (88%)	.053	—
Prolapse > 1 Ant Seg	50 (33%)	12 (75%)	.002	—
Prolapse > 1 Post Scal	71 (46%)	14 (88%)	.003	—
Prolapse >1 segments/scal on both leaflets	36 (23%)	12 (75%)	.001	—

Prolapse ≥ 3 segments/scal	68 (44%)	13 (81%)	.007	—
Complex repair	95 (61%)	6 (38%)	.11	

A

Annular dil/Ca, Mitral annular diameter >5 cm or annular calcification; *Ant seg*, anterior segment; *Complex repair*, mitral valve repair using chordal replacement or transfer; *LVEF*, left ventricular ejection fraction; *MR*, mitral regurgitation; *NYHA*, New York Heart Association functional class; *Post scal*, posterior scallop; *TEE*, transesophageal echocardiography

As mitral annular diameter more than 5 cm and presence of annular calcification were both significant univariate predictors and were correlated with each other, they were combined during multivariate analysis. Logistic regression analysis identified 3 independent TEE predictors of unsuccessful MV repair: central mitral regurgitant jet (odds ratio 8.8; 95% confidence limits 2.3-33.9); mitral annular diameter more than 5 cm or the presence of annular calcification (odds ratio 4.0; 95% confidence limits 1.2-13.3); and 3 or more segments/scallop with prolapse or flail (odds ratio 7.4; 95% confidence limits 1.5-36.1). The logistic regression model had good discriminative accuracy (C statistic = 0.85). These independent predictors were incorporated into a point score that gave equal weights to each of the risk factors. The estimated risk of unsuccessful MV repair with 0, 1, or more than 1 predictors was 2%, 12%, and 50%, respectively. The corresponding rate of unsuccessful MV repair was 0%, 10%, and 36% (Figure 6).

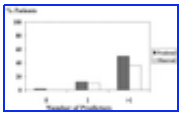

Fig. 6. Predicted and observed rates of unsuccessful mitral valve repair as function of number of predictors. There were 72, 73, and 25 patients in risk group corresponding to presence of 0, 1, and greater than 1 predictors.

The C statistic of the point score was 0.83, showing that there was little loss in discriminative accuracy when all 3 factors were weighted equally. The C statistic was similar (0.84) when a point score with unequal weights (annular dilatation or calcification given a lower weight than the other 2 predictors) was used. When the logistic regression was cross-validated on the entire study population using bootstrap method, the results were similar to that of the original model (odds ratio 8.9, 3.8, and 8.2 for central mitral regurgitant jet, mitral annular diameter > 5 cm or calcified annulus, and ≥ 3 prolapse/flail segments/scallop, respectively). The 95% confidence limits from bootstrap method (4.9-13.5, 2.2-6.1, 4.5-13.5 for central mitral regurgitant jet, mitral annular diameter > 5 cm or calcified annulus, and ≥ 3 prolapse/flail segments/scallop, respectively) encompassed the odds ratios from the original model.

LV systolic function at the completion of MV operation was normal, mildly, and moderately reduced in 65%, 29%, and 6% of patients, respectively. In 26% of the patients who had a successful MV repair, no mitral regurgitation was seen on the postrepair TEE; the remaining patients had trace to mild mitral regurgitation. No systolic anterior motion of the MV was seen in 89% of patients; the remainder had mild systolic anterior motion with no significant LV outflow tract obstruction. The MV area was 2.5 cm^2 or greater, 2 to 2.4 cm^2 , and 1.5 to 1.9 cm^2 in 70%, 27%, and 3%, respectively, of patients at the end of MV repair.

On their predischarge transthoracic echocardiogram, 18% of patients had no mitral regurgitation; 81%, and 1% of patients had mild and moderate mitral regurgitation, respectively. Predischarge LV systolic function was normal, mildly reduced, moderately, or severely reduced in 66%, 26%, 7%, and 1% of patients, respectively. The 30-day survival after MV operation was 100%.

Discussion

With advances in surgical technique, MV repair has become the procedure of choice in patients with significant mitral regurgitation from MV prolapse.[7] [16] Compared with medical therapy, patients with flail MV who are undergoing early repair have better long-term survival and a reduced incidence of nonfatal cardiac complications.[2] [3] Despite the excellent success rate of MV repair at most institutions, the technical demands of MV repair are higher than that for MV replacement and vary with MV morphology. In particular, anterior MV prolapse/flail requires a more complex repair than isolated disease of P2.[16] Therefore, MV morphology is crucial in determining the feasibility, timing, and complexity of repair. In this prospective study of 170 patients undergoing MV repair for MV prolapse, we have demonstrated that there was excellent agreement between TEE and surgical findings in identifying the site and extent of MV disease. We also identified 3 TEE predictors of unsuccessful repair and derived a clinical prediction rule that can assist physicians in assessing the feasibility of MV repair.

Previous studies have examined the accuracy of TEE in identifying abnormal MV anatomy in patients undergoing MV operation.[12] [14] In these previous studies that were retrospective, studied a small number of patients, or examined patients with MV disease as a result of several disease states, accuracy of TEE in the identification of segmental disease have ranged from 70% to 96%. Thus, the accuracy of TEE in our study was comparable with that of previous published studies. Furthermore, the current study extends the results of previous studies by prospectively examining the accuracy of TEE in delineating MV morphology in a large group of patients with myxomatous disease undergoing MV repair. This study also demonstrated that MV repair by experienced surgeons has an excellent success rate even in the case of anterior leaflet involvement or extensive bileaflet disease.

Several imaging protocols for TEE identification of MV leaflets have been proposed. [12] [15] [23] We adapted the protocol described by Foster et al[12] in this study. In contrast to the original protocol published by Foster et al,[12] we simplified the protocol by sequential rotation of the transducer within the midesophagus without additional anteflexion or retroflexion. Despite the simplification of the protocol, the agreement between TEE and surgical findings remains high. This agreement was best for A2 or P2, reflecting the relatively large area of these 2 segments. Although we also use transgastric imaging as recommended by recently published American Society of Echocardiography/Society of Cardiac Anesthesia guidelines,[23] the incremental accuracy of transgastric imaging in defining MV morphology was not evaluated in this study.

In this study we demonstrated the predictive role of TEE in assessing the feasibility of MV repair by surgeons with recognized expertise in valve repair. Central mitral regurgitant jet direction, annular calcification and marked dilatation, and extensive leaflet disease (3 or greater prolapsed or flail segments/scallops seen on TEE) were independent predictors of unsuccessful MV repair. As posteriorly directed mitral regurgitant jet is seen with isolated anterior MV prolapse/flail and the converse is true with isolated posterior MV prolapse/flail, a central regurgitant jet is the result of bileaflet disease. The relationship between leaflet extent and unsuccessful MV repair may be mediated by the need for a complex repair with the use of artificial chordae and its relationship with bileaflet disease. Annular abnormalities may be a result of extensive MV disease, LV dilatation, or aging.

Repair of posterior MV prolapse has excellent immediate and long-term outcome and commonly involves leaflet resection and annuloplasty.[24] [25] Posterior leaflet repair alone may be sufficient in patients with bileaflet prolapse in which there is no significant anterior chordal disease.[26] However, many patients with bileaflet prolapse have anterior chordal disease and will require additional procedures such as chordal shortening, transfer, or replacement using artificial chordae.[16] [27] [29] Chordal transfer has also been reported to be a safe and effective method for repair of anterior or bileaflet prolapse.[28] The durability with the use of artificial chordae was reported to be superior to that with chordal shortening. [29] A previous study demonstrated that chordal replacement had no adverse outcome on the late outcome after MV repair. [16] Most patients in our study requiring additional MV repair underwent chordal replacement, reflecting the excellent results with use of artificial chordae reported by our center and others.[16] [30] Regardless of the type of MV

repair that is required, our study results will allow the accurate identification of diseased segments so that the surgical approach can be matched to the expertise of the cardiac surgeon.

Application of our study results to determining feasibility of MV repair at the time of the office consultation assumes that intraoperative TEE findings will be identical to a study performed in an outpatient setting. Unfortunately, most patients referred for MV repair at our center did not undergo TEE examination of MV morphology at our center before their intraoperative study. Although 1 study has reported that the severity of mitral regurgitation in myxomatous disease was not significantly affected by loading conditions,[31] concordance between our intraoperative TEE results and those obtained from preoperative TEE will require further investigation. The prediction rule developed in this study will also need to be validated in an independent population. As the patients in this study underwent MV repair by surgeons with recognized expertise in valvular repair, the prediction rule may not be generalizable to centers performing MV repair using other techniques. However, the ability to accurately predict the site and extent of MV disease will allow appropriate referral to surgeons with the required expertise.

In conclusion, intraoperative multiplane TEE provides a comprehensive assessment of MV leaflet morphology and can predict the feasibility of repair. If our study findings can be extended to the preoperative setting, then preoperative TEE can be used to optimize patient selection and timing of operation. Asymptomatic patients with limited disease localized to the posterior segment can be referred for early repair and a high success rate can be anticipated. Conversely, early operation may not be advisable in those with extensive disease or with other unfavorable morphologic characteristics, unless the surgical center has recognized expertise in complex valve repair.

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