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Valve Disease

Functional Anatomy of Mitral Regurgitation

Accuracy and Outcome Implications of Transesophageal Echocardiography

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OBJECTIVES This study was performed to determine the accuracy and outcome implications of mitral regurgitant lesions assessed by echocardiography.

BACKGROUND In patients with mitral regurgitation (MR), valve repair is a major incentive to early surgery and is decided on the basis of the anatomic mitral lesions. These lesions can be observed easily with transesophageal echocardiography (TEE), but the accuracy and implications for outcome and clinical decision-making of these observations are unknown.

METHODS In 248 consecutive patients operated on for MR, the anatomic lesions diagnosed with TEE were compared with those observed by the surgeon and those seen on 216 transthoracic echocardiographic (TTE) studies, and their relationship to postoperative outcome was determined.

RESULTS Compared with surgical diagnosis, the accuracy of TEE was high: 99% for cause and mechanism, presence of vegetations and prolapsed or flail segment, and 88% for ruptured chordae. Diagnostic accuracy was higher for TEE than TTE for all end points ($p < 0.001$), but the difference was of low magnitude (<10%) except for mediocre TTE imaging or flail leaflets (both $p < 0.001$). The type of mitral lesions identified by TEE (floppy valve, restricted motion, functional lesion) were determinants of valve repairability and postoperative outcome (operative mortality and long-term survival; all $p < 0.001$) independent of age, gender, ejection fraction and presence of coronary artery disease.

CONCLUSIONS Transesophageal echocardiography provides a highly accurate anatomic assessment of all types of MR lesions and has incremental diagnostic value if TTE is inconclusive. The functional anatomy of MR defined by TEE is strongly and independently predictive of valve repairability and postoperative outcome. Therefore, the mitral lesions assessed by echocardiography represent essential information for clinical decision making, particularly for the indication of early surgery for MR. (J Am Coll Cardiol 1999;34:1129–36) © 1999 by the American College of Cardiology

Patients with mitral regurgitation (MR) often are asymptomatic despite severe MR but incur a high risk of left ventricular (LV) dysfunction (1,2). This complication is associated with a dismal outcome and is imperfectly predictable (1–4). Therefore, it was proposed recently that surgery should be performed early in patients with MR (5), even before the occurrence of LV dysfunction or symptoms (4). Furthermore, in specific valvular lesions such as flail leaflets, which are associated with high risk under conservative management (6), early surgery may provide improved long-term outcome (7). This early surgical approach depends on identifying patients who are at low operative risk and have a high probability of good long-term outcome and, thus, is closely dependent on repairability of the mitral valve (8). Consequently, current recommendations for surgical correction of MR make valve repairability the centerpiece of the clinical decision (9). However, there are no widely accepted criteria for valve repair (10), and the feasibility of repair depends on the anatomic lesions of the valve (11), underscoring the importance of accurately defining the functional anatomy of MR for clinical decision making.

Transesophageal echocardiography (TEE) provides excellent real-time visualization of heart anatomy, especially the mitral valve (12). In MR, intraoperative TEE is valuable in diagnosing residual MR (13,14) and complications such as systolic anterior motion (15) after valve repair. However, the role of echocardiographic assessment of functional mitral anatomy in MR is unclear, because its accuracy in diagnosing anatomic lesions and its predictive value for valve repairability and postoperative outcome have not been

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Abbreviations and Acronyms

LV = left ventricle
MR = mitral regurgitation
TEE = transesophageal echocardiography
TTE = transthoracic echocardiography

well defined. The pilot studies that have considered these issues were limited by their small size (16), the selected lesions examined (17,18) and the lack of information on outcome, and may not have reflected routine practice. These studies also lacked agreement about the best approach for making the important diagnosis of flail leaflets (19,20).

To determine the accuracy and implications of mitral regurgitant lesions assessed by echocardiography, we examined, in our consecutive experience in routine clinical practice, the accuracy of TEE compared with surgical assessment, its incremental accuracy over TTE and the implications of TEE findings for valve repairability and postoperative outcome.

METHODS

Population. The inclusion criteria were: 1) presence of isolated, acquired, pure MR; 2) surgical correction with opening of the left atrium and direct examination of the lesions by a surgeon between January 1, 1988 and December 31, 1991; and 3) TEE performed in routine clinical practice at our institution before surgical correction of MR.

The exclusion criteria were: 1) associated aortic or tricuspid valve disease requiring valve replacement, 2) associated mitral stenosis, and 3) associated congenital heart disease. No patients were excluded on the basis of age, gender, LV function or cause of MR.

Anatomic mitral regurgitant lesions. The anatomic mitral lesions were diagnosed according to previously established criteria for direct observation (21) and echocardiography (22,23). The description of the functional anatomy of MR used a uniform transcription, unaltered from the reports dictated by the surgeon and physician performing the echocardiographic examination in an on-line data entry system. The echocardiographic tapes were not reinterpreted. An equivocal description or the absence of a description was considered as unknown. The surgeons were aware of all tests and echocardiograms but were not aware of the study, and the operation performed was based on the anatomic assessment of the lesions, which were reported as observed.

The anatomic lesions were noted from the preoperative report when available. Intraoperative TEE findings were recorded before the initiation of bypass, and the interpretation was dictated immediately. The postbypass TEE findings were dictated separately. Therefore, the anatomic assessment of mitral lesions by echocardiography was independent of the surgical observations.

The functional anatomy of MR was analyzed according to both a gross anatomic classification (as floppy valve, other organic lesion [rheumatic lesions, endocarditis, annular calcification, valve sclerosis or distortion and inflammatory disease] and ischemic or functional lesions) and a detailed anatomic assessment (specific cause, specific mechanism and presence of vegetations, and the presence and leaflet localization of a valve prolapse, flail leaflet and ruptured chordae).

Degree of MR. The degree of MR assessed by echocardiography was based on color flow imaging (24,25) and recording of pulmonary venous flow (26), and was reported in four grades. The angiographic assessment of the severity of regurgitation was based on the presence and density of dye in the left atrium after injection into the left ventricle (27). The angiographic and Doppler echocardiographic grades of MR were recorded as noted by the physician who interpreted the tests when they were performed and were not reinterpreted for the present study.

Postoperative outcome. Follow-up information was obtained by review of the medical records of the patients followed at our institution and by questionnaires and telephone interviews of the other patients and their families and physicians. Follow-up was complete up to 1997, or death for 246 patients (99%). The outcome events analyzed were operative mortality, completion of valve repair, long-term survival and recurrence of heart failure.

Statistics. Baseline characteristics are presented as mean ± standard deviation. Comparisons between groups were performed using analysis of variance, two-tailed t test, and chi-square test. The accuracy of echocardiography was determined using surgical observations as reference and was analyzed for both gross anatomic classification and detailed anatomic assessment. Uncertain echocardiographic diagnoses were considered errors. Sensitivity, specificity, positive and negative predictive values and overall accuracy were calculated. For the comparison of accuracy of TTE and TEE, the percentage of patients with incremental accuracy of TEE over TTE was calculated as the ratio of the difference between their accurate diagnoses to the total number of cases examined, and tested using McNemar's test. Subgroup analysis was performed according to completeness and findings of TTE. The incremental accuracy of TEE was tested for equality of proportion of cases corrected by TEE with use of the chi-square test. The agreement and kappa coefficients among TTE, TEE and LV angiography for the grading of MR were calculated and compared using McNemar's test. Postoperative outcome was reported as percentages of events, using if appropriate the Kaplan-Meier method, and compared using proportional hazards or logistic regression with and without adjustment for age, gender, LV ejection fraction and presence of coronary artery disease. Potential referral biases were analyzed using chi-square tests. First, accuracy of TEE was compared between patients with and without TTE and between patients locally

Table 1. Baseline Characteristics of the Overall Group and Subgroups Defined by Gross Anatomic Classification by Transesophageal Echocardiography

Variables/patients	Group				p
	Overall (n = 248)	Floppy Valve (n = 181)	Organic Nonfloppy (n = 35)	Ischemic or Functional (n = 32)	
Age (years)	64 ± 14	64 ± 14	61 ± 17	69 ± 9	0.054
Sex (% men)	61	69	20	59	0.001
NYHA class III-IV (%)	51	46	60	66	0.001
SBP (mm Hg)	129 ± 20	130 ± 19	125 ± 20	129 ± 24	0.40
Afib (%)	35	35	43	25	0.31
Creatinine (mg/dl)	1.3 ± 0.8	1.2 ± 0.8	1.3 ± 1.2	1.6 ± 0.9	0.11
Cholesterol (mg/dl)	203 ± 49	201 ± 40	201 ± 72	217 ± 59	0.35
CAD (%)	35	26	31	91	0.001
LA diameter (mm)	54 ± 10	54 ± 10	52 ± 9	52 ± 14	0.55
EF (%)	60 ± 12	63 ± 10	58 ± 13	45 ± 12	0.001

Afib = atrial fibrillation; CAD = coronary artery disease; EF = ejection fraction; LA = left atrium; NYHA = New York Heart Association; SBP = systolic blood pressure.

and distantly referred (using a threshold of 120 miles from Rochester, MN); second, accuracy of TTE was compared between the patients of the present series and those operated on during the same period without TEE; and third, the distribution of causes of MR was compared between the present series and a group of 254 patients examined as outpatients for isolated grade 3 or 4 MR. A p value < 0.05 was considered significant.

RESULTS

Baseline characteristics. During the study period, 248 consecutive patients (64 ± 14 years old; 61% men) fulfilled the study criteria. The cause of the regurgitation determined by comprehensive assessment was rheumatic disease in 11 patients, endocarditis in 14, ischemic heart disease in 29, cardiomyopathy in 3, floppy mitral valve in 179 and a miscellaneous cause in 12. The baseline characteristics are presented in Table 1. Mitral valve repair was performed in 209 patients (84%) and valve replacement in 39. Coronary artery bypass surgery was performed concomitantly in 83 patients (34%). TEE was performed in an outpatient setting in 29 patients, intraoperatively in 190 and in both settings in 29. In 216 patients, TTE was performed preoperatively. All aspects of functional anatomy of MR were described by TTE, TEE and surgery in more than 97% of patients.

Functional anatomic assessment. SURGICAL OBSERVATIONS. The gross anatomic classification made by the surgeon was floppy mitral valve in 179 patients, other organic cause in 37 (rheumatic in 11, endocarditis in 14 and miscellaneous causes in 12) and ischemic or functional lesion in 32 (normal leaflets and chordae with annular enlargement in all, with myocardial necrosis or scarring in 29). The major mechanism of MR observed by the surgeon, in addition to universal annular enlargement, was reduced leaflet mobility (leaflet thickening and chordal shortening) in 12 patients, perforation in 6, incomplete coaptation (tethering and separation of normal leaflets by excessive subvalvular traction) in 24, ruptured papillary muscle in 6, excessive leaflet mobility (insufficient subvalvular support without ruptured papillary muscle) in 190, miscellaneous mechanism in 9 and unknown mechanism in 1. Vegetations were present in 11 patients. Valve prolapse (displacement of any leaflet part beyond the annular plane) was noted in 205 patients and was located on the posterior, anterior or both leaflets in 117, 30 and 58 patients, respectively. A flail segment (eversion of leaflet tip into the left atrium) was present in 171 patients and located on the posterior, anterior or both leaflets in 137, 27 and 7 patients, respectively. Ruptured chordae (with visible remnants) were observed in 152 patients and located on the posterior, anterior or both leaflets in 126, 19 and 7 patients, respectively. Of note, in 13 patients with flail leaflet and no ruptured papillary muscle, no residual ruptured chordae were visible to the surgeon.

Diagnostic accuracy of TEE. The gross anatomic classification by TEE compared with surgery was accurate in 99% of cases, with two false positives for floppy valves, which were also false negatives for other organic mitral diseases. The classification as ischemic or functional lesion was 100% accurate.

The comparison of TEE with surgical observations regarding detailed anatomic assessment of each etiology and mechanism of regurgitation was accurate in 246/248 (99%) and 244/247 (99%), respectively. Accuracy of TEE was >90% for all other specific lesions examined except for ruptured chordae (88%) (Table 2). After a positive diagnosis, the localization of the prolapsing valve, flail leaflets or ruptured chordae to the anterior, posterior or both leaflets was also highly accurate.

Incremental value of TEE. The accuracy of TTE was high (Table 3). However, in the 216 patients who underwent imaging by both modalities, the accuracy of TEE was significantly higher (Table 3). The percentage of errors of TTE corrected by TEE was >70% for all end points (Table 3). However, the incremental accuracy of TEE was usually

Table 2. Diagnostic Value of Transesophageal Echocardiography for Specific Mitral Valve Lesions

Lesion	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Overall Accuracy (%)*	Localization Accuracy (%)
Vegetations	82	99	90	99	99	—
Prolapse	99	98	99	98	99	93
Flail	100	99	99	100	99	96
Ruptured chordae	84	95	96	78	88	96

*Overall accuracy for etiology and mechanism was 99%.
NPV = negative predictive value; PPV = positive predictive value.

low (<5%) except for ruptured chordae (32%) and flail leaflets (16%).

To identify subgroups with high and low incremental value of TEE, we analyzed groups defined by the TTE findings. The incremental accuracy of TEE over TTE was lower when the physician performing TTE construed the anatomic assessment to be complete (group 1, n = 177) rather than possibly incomplete (group 2, n = 39) (Table 3). The incremental value of TEE was also highest when TTE diagnosed simple prolapse without flail leaflet (57% vs. 8.7% in patients without evidence of prolapse and 1.7% in patients diagnosed by TTE to have flail leaflets, $p < 0.001$).

Degree of regurgitation. LV angiography was performed in 138 patients, and assessment of MR was possible in 131. MR was grade 2 in 3 patients, grade 3 in 21 and grade 4 in 107. The agreement with angiography was perfect (same grade) in 76% (kappa = 0.36) and 64% (kappa = 0.21) for the gradation by TEE and TTE ($p = 0.04$), respectively, and was within one grade in 95% and 92% ($p = 0.76$).

Outcome according to anatomic classification. The outcome according to the anatomic classification by TEE is presented in Table 4. For all end points (operative mortality, mitral repair performed, five-year survival [Fig. 1] and five-year incidence of heart failure), the gross anatomic classification was significantly associated with outcome in univariate analysis. There was also a trend for shorter length of hospital stay in patients with floppy valves (12 ± 11 days vs. 17 ± 15 in organic non-floppy and 14 ± 10 in ischemic/functional MR, $p = 0.09$). Patients with floppy valves, despite their age (Table 1), demonstrated excellent outcome, with 1.7% operative mortality, 90% valve repairability and 86% five-year survival.

In multivariate analysis, these results were confirmed and the anatomic classification by TEE remained significantly and independently associated with outcome after adjustment for age and gender for all end points and after adjustment for age, gender and ejection fraction for operative mortality, performance of valve repair and long-term survival (Table 4). Even after additional adjustment for the presence of coronary artery disease, the gross anatomic classification remained a significant predictor of operative mortality ($p = 0.046$) and valve repair ($p = 0.036$), and had a borderline significance for long-term survival ($p = 0.065$).

Influence of referral patterns. The accuracy of TEE was not different for the 216 patients with and the 32 without preceding TTE (all $p > 0.10$). The accuracy of TTE was not different for the 216 patients with and the 79 without TEE operated on during the same period (all $p > 0.13$). Therefore, the accuracies of TEE and TTE were independent of each other.

Table 3. Incremental Diagnostic Value of Transesophageal Over Transthoracic Echocardiography in Mitral Regurgitant Lesions

	Overall series					Subgroup Analysis: Incremental Accuracy (%)		
	Accuracy							
Anatomic Lesion	TEE (%)	TTE (%)	p Value	Incremental Accuracy (%)	Error Correction (%)*	Group 1 (n = 177)	Group 2 (n = 39)	p Value
Etiology	99	95	0.008	3.7	80	1	15	< 0.001
Mechanism	99	94	0.002	4.6	77	1	21	< 0.001
Vegetations	99	95	0.008	3.7	73	1	15	< 0.001
Prolapse	99	95	0.004	4.2	82	2	15	< 0.001
Flail segment	99	83	< 0.001	16	97	7	59	< 0.001
Ruptured chordae	88	57	< 0.001	32	76	24	70	< 0.001

*Error correction reports the percentage of errors by TTE corrected by TEE. Groups are defined on the basis of anatomic assessment construed by the physician performing the test as complete (group 1) or possibly incomplete (group 2).
TEE = transesophageal echocardiography; TTE = transthoracic echocardiography.

Table 4. Outcome of Surgery According to Gross Anatomic Classification by Transesophageal Echocardiography

Etiology by TEE	No. of Patients	Operative Mortality (%)	Valve Repair Performed (%)	5-Year Survival Rate	5-Year Heart Failure Rate
Floppy valve	181	1.7	90	86 ± 3	13 ± 3
Organic nonfloppy	35	5.7	63	69 ± 8	16 ± 7
Ischemic/functional	32	15.6	75	50 ± 9	38 ± 10
p unadjusted		0.001	0.001	< 0.001	0.001
p adjusted for age and sex		0.002	0.005	< 0.001	0.007
p adjusted for age, gender and EF		0.003	0.003	0.02	0.47

EF = left ventricular ejection fraction; TEE = transesophageal echocardiography.

The accuracy of TEE and TTE was not different whether the patient was locally or distantly referred (all $p > 0.10$). In the distribution of causes of MR between the present series and the 254 outpatients with similar MR, no significant difference was observed ($p = 0.18$). Therefore, there was no evidence that referral patterns may have influenced the accuracy of either TTE or TEE or the distribution of causes of MR.

The performance of valve repair was dictated by the lesions surgically observed and was not different whether intraoperative TEE was performed or not ($p = 0.14$), and showed a low frequency of recurrent MR at last follow-up (4.8% vs. 2.6% for valve replacement, $p = 0.54$).

DISCUSSION

The present study of a large number of patients undergoing MR surgery shows that for the assessment of the functional anatomy of MR, the accuracy of TEE is excellent both for gross anatomic classification and detailed anatomic assessment of the mitral lesions. The incremental accuracy of TEE over TTE is significant but reaches high magnitude in limited subsets of patients, depending on the results of TTE.

The anatomic classification provided by echocardiography is a strong predictor of valve repairability, operative mortality and long-term outcome even after adjustment for other important predictors of outcome. Therefore, the functional anatomy of MR defined by echocardiography is of major importance for clinical decision making, particularly for the indication of early surgery.

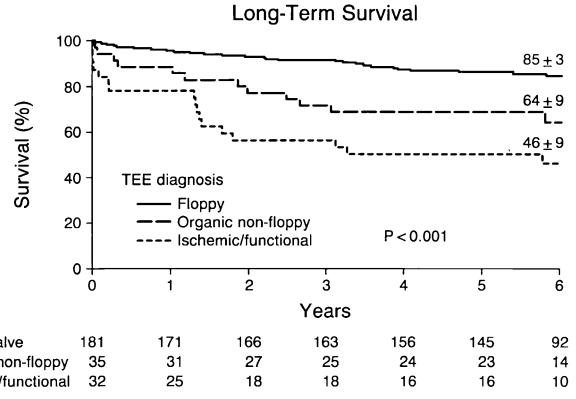

Figure 1. Postoperative survival according to anatomic classification by transesophageal echocardiography (TEE) in three groups: floppy valves, organic nonfloppy and ischemic/functional mitral regurgitation (MR).

Functional anatomy of MR. Echocardiography, particularly TEE, provides excellent imaging of the mitral valve apparatus (12), but the importance of accurately assessing functional anatomy of MR and using it in clinical decision making has become critical recently for several reasons. First, the management of severe MR has changed profoundly, because of the high incidence (1,2) and poor prognosis (2–4) of LV dysfunction due to MR. Surgery in asymptomatic patients is now accepted (4,5,9) if an optimal postoperative result can be obtained (7). Valve repair is essential to optimal results because of low operative mortality (28,29) and better long-term outcome than valve replacement (8). A high likelihood of successful valve repair is an incentive to perform early surgery (7). Valve repair is more feasible because of new surgical techniques (30), but it cannot be performed in all patients, and valve lesions are critical data that a surgeon needs in order to determine the likelihood of repair (10,11,31). Second, the potential benefits of surgery may vary greatly depending on the cause of MR (3,6). In particular, patients with flail leaflets who are at relatively high risk with conservative management (6) are candidates for early surgery, which appears to improve their outcome (7). This rationale underscores the importance of evaluating the accuracy of echocardiographic assessment of MR functional anatomy and suggests that it may have outcome implications.

The accuracy of anatomic assessment of mitral lesions by TEE (16,17,19) compared with direct examination has been analyzed in series limited by their small size. The incremental accuracy of TEE over TTE in these pilot reports was not observed consistently (19,32), was noted for limited anatomic lesions (17,18,20,33) and may have been the result of poor and unexpectedly low (22,34) performance of TTE. Furthermore, the influence of the functional anatomy of MR diagnosed by echocardiography on postoperative outcome has not been fully defined.

In the present study with a large number of patients with all types of lesions, the accuracy of TEE compared with

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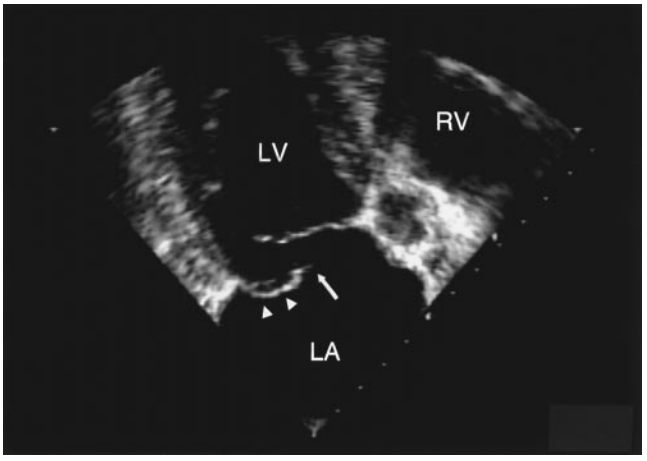

Figure 2. Example of flail posterior mitral leaflet **(arrowheads)** with visible small ruptured chordae **(arrow)** viewed from the long-axis view (LA = left atrium; LV = left ventricle; RV = right ventricle).

surgical observation was high for all end points, and even for direct visualization of remnants of ruptured chordae, approaching 90%. These thin floating echoes (Fig. 2) (17,18) can occasionally be missed, but it is most important that the usually associated flail leaflets are correctly diagnosed (19). This high accuracy of echocardiographic diagnosis of all types of mitral regurgitant lesions makes echocardiography essential for clinical decision making in patients with MR.

Both TTE and TEE provide a high degree of accuracy. The incremental accuracy of TEE over TTE is significant but of variable magnitude. For most end points, the incremental value of TEE was low because of the excellent performance of TTE (Table 3). In the present population, vegetations were large, and the incremental value of TEE may be higher with smaller vegetations (35,36). The incremental diagnostic value of TEE for flail mitral leaflets was significant (20) and of notable magnitude (16%) despite a relatively good performance of TTE (22,34). Therefore, uncertainties about the TTE anatomic diagnosis, particularly for flail leaflets, are usually clarified by TEE (19,20), which in these circumstances has a high incremental value. However, in most cases, when TTE is construed as complete, TEE provides little incremental value and is not indispensable for the assessment of the functional anatomy of MR.

Degree of regurgitation. TTE, TEE and LV angiography were performed in routine practice, that is, not simultaneously. The agreement among the three techniques was imperfect. This result is in contrast with that of pilot studies on TEE grading of MR (25,26,37–39). However, similar discrepancies are more common in routine practice (40). These discrepancies in the grading of the degree of regurgitation require the integration of numerous signs and methods (41). The important limitations of qualitative assessment of MR have led to the development of quantitative methods using the transesophageal (42,43) or transthoracic (44) approach that have yet to be evaluated in routine practice.

Functional anatomy and outcome of MR surgery. A relationship between the gross anatomic classification of MR and surgical outcome has been suggested in previous studies (45), but has been uncertain because of the lack of adjustment for LV function (3), especially important in ischemic MR (46). The applicability of old data (45,46) to the current practice is also questionable in the era of valve repair (8,11).

To our knowledge, the present study is the first to demonstrate the association between echocardiographic anatomic classification and postoperative outcome, an observation critical for the current clinical decision-making process (9). The influence of the echocardiographic diagnosis on outcome is due partly to its relationship with LV dysfunction, particularly regarding the recurrence of postoperative heart failure (3). However, multivariate analysis confirmed the significant relationship between anatomic classification by TEE and outcome for operative mortality, performance of valve repair (11) and long-term survival (3), even after adjustment for age, gender, LV ejection fraction and presence of coronary artery disease. Furthermore, the possibility that the gross anatomic classification may be a surrogate predictor for another variable is moot. Patients with a floppy valve diagnosed by echocardiography are prime candidates for early surgery because the risk of surgery is very low, the rate of valve repair is very high and long-term survival is good (7,9). Conversely, patients with functional MR or MR due to ischemic heart disease have a much higher risk and, if asymptomatic, do not appear to be good candidates for surgery (3). For patients with other organic nonfloppy lesions, the case for early surgery should be evaluated carefully and individually (9). Therefore, the anatomic substrate of MR described by echocardiography is strongly and independently predictive of the procedure performed and the outcome of surgery. Therefore, it should be described accurately in the evaluation of MR and should be an integral part of the decision-making process (9).

Study limitations. The study was based on routine clinical practice and focused only on lesions consistently described and relevant to surgical decision making (11). The high accuracy of TEE was obtained with examining physicians unaware of the study and reflects routine clinical practice. The surgical observations were not blinded to echocardiographic results, but were not aimed at matching those but rather at defining the possibility of repair. The fact that valve repair was highly successful when performed and rarely complicated by recurrent MR confirms the low probability of bias associated with this study design.

The anatomic characteristics described are related but not synonymous. The cause and mechanism of MR should be distinguished; for example, patients with endocarditis as the cause of MR may have either leaflet perforations or ruptured

chordae as the mechanism of MR. Also, visualization of flail leaflets and ruptured chordae remnants are not strictly synonymous, as shown in the surgical results section.

The prediction of valve repair is an end point highly dependent on the surgeon's skill and cannot be generalized (10), but each surgeon, to determine his specific likelihood of repair, can use a reliable anatomic description (29). The fact that the gross anatomic classification was predictive of repairability is not unique to our center (10), but the gross classification used is simple and generalizable to other centers. However, specific repair percentages achieved should be determined at each institution.

The study did not focus on a specific type of echocardiographic equipment. The high accuracy of TEE was observed relatively early in our experience, was not dependent on a specific technology and is widely applicable. Further improvements in diagnostic accuracy for ruptured chordae provided by new technology should be documented in future studies.

Referral bias may be thought to affect the results. With the observed sensitivity and specificity, changes in prevalence would lead to minimal changes in incremental accuracy, and referral patterns did not influence the results. The present results apply only to patients with clinically significant MR (mostly grade 3 or 4) and should not be extrapolated to other populations with mild MR or other referral diagnoses (35,36). However, the present population is representative of patients with grade 3 or 4 MR in whom decision making requires the most precise anatomic assessment.

Clinical implications. Transesophageal echocardiography provides a highly accurate gross anatomic classification and detailed anatomic assessment of MR lesions. The incremental diagnostic accuracy of TEE over TTE is significant but reaches high magnitude in selected subsets of patients defined according to the results of TTE. The anatomic classification provided by echocardiography is a strong and independent determinant of the repairability of the mitral valve, operative mortality and long-term postoperative outcome. Therefore, the echocardiographic anatomic classification of MR is an essential component of clinical decision making, particularly in deciding about early surgery for asymptomatic patients.

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