Improved Evaluation of the Location and Mechanism of Mitral Valve Regurgitation with a Systematic Transesophageal Echocardiography Examination

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Mitral regurgitation (MR) is a major determinant of outcome in cardiac surgery. The location and mechanism of mitral lesions determine the approach to various repairs and their feasibility. Because of incomplete evaluations or change in patient condition, detailed intraoperative transesophageal echocardiography (TEE) examination of the mitral valve may be required. We hypothesized that a systematic TEE mitral valve examination would allow precise identification of the anatomic location and mechanism of MR in patients undergoing mitral surgery. We designed a systematic mitral valve examination consisting of six views: five-chamber, four-chamber, two-chamber anterior, two-chamber mid, two-chamber posterior and short-axis. We used this examination prospectively in 13 patients undergoing mitral valve surgery for severe MR and compared the results with the surgical findings. We then retrospectively interpreted 11 similar patients who had undergone intraoperative TEE studies before this examination. TEE correctly diagnosed the mechanism and precise location of pathology in 12 of 13 patients in the prospective group, but in only 6 of 10 patients in the retrospective group. TEE also correctly identified 75 of 78 mitral segments (96%) as being normal or abnormal. In the retrospective group, only 42 of 60 segments (70%) were correctly identified ($P < 0.001$). We conclude that this systematic TEE mitral valve examination improves identification of mitral segments and precise localization of pathologies and may also improve the diagnosis of the mechanism of MR. **Implications:** In this article, we describe how a systematic examination of the mitral valve by using transesophageal echocardiography allows identification of the different segments of the mitral valve, precise localization of pathology, and helps to diagnose the mechanism of mitral regurgitation. This is important in determining an approach to mitral valve repair and its feasibility.

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The presence and severity of mitral valve regurgitation (MR) are major determinants of outcome in cardiac surgical patients (1). The mechanism of MR is also important in determining whether surgical correction is necessary and whether repair or replacement is warranted. For example, moderate ischemic MR often improves after coronary bypass, whereas MR from significant leaflet prolapse does not (2). Ideally, the surgical plan should be revised before cardiopulmonary bypass to include mitral valve repair whenever intraoperative echocardiography indicates that hemodynamically significant MR will likely persist without definitive treatment.

Mitral valve repair has many proven advantages over mitral valve replacement (3,4), but its feasibility depends on the location, extent, and mechanism of MR (5). For example, repair of posterior leaflet prolapse is generally easier than anterior or bileaflet prolapse or prolapse involving the paracommissural areas (4,6,7). Anterior leaflet pathology also may not be suitable for minimally invasive techniques.

Because the preoperative assessment of mitral valve pathology may be incomplete or the condition of the patient may have changed, anesthesiologists may be called on to assess the mitral valve by using transesophageal echocardiography (TEE) in the operating room at the time of surgery.

Therefore, we developed a systematic mitral valve examination and hypothesized that this examination would improve intraoperative identification of mitral segments, precise localization of lesions, and determination of the mechanism of MR.

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Methods

We defined a systematic examination of the mitral valve using a minimal number of cross-sections that allow clear delineation of the three scallops of the posterior leaflet and the juxtaposed segments of the anterior leaflet, according to a nomenclature popularized by Carpentier et al. (8). This nomenclature, illustrated in Figure 1, has been used at our institution for several years to describe the location of mitral valve lesions.

For all the following descriptions, the images are oriented with the apex of the sector scan at the top of the video screen; in the transverse cross-sections, the patient's right is on the left side of the screen, and the patient's left is on the right side of the screen; in the longitudinal cross-sections, the anterior structures are on the right side of the screen and the posterior structures are on the left side (Table 1 describes the technical terms used to describe the movements of the probe).

Figure 2 shows the planes of the different TEE cross-sections. Figure 3 shows a graphic representation of the following examination sequence and gives a detailed account of the planes of the cross-sections and the structures seen in each view.

The two-dimensional examination consists of a sequence of six steps. It begins with the transducer at 0° and slight anteflexion of the probe in the lower esophagus. This is the five-chamber cross section, and it depicts the anterior structures of the mitral valve (Figure 3). From this view, the probe is retroflexed and may need to be advanced slightly until the left ventricular outflow tract disappears: this is the four-chamber cross-section. In this view, the posterior structures of the valve are visualized (Figure 3). Without changing the position of the probe, the axis of the transducer is rotated ("motored") to 90° to obtain the longitudinal cross-sections. The shaft of the probe is then slightly turned toward the patient's right (clockwise rotation) until no mitral coaptation point is seen, and the plane cuts through the anterior mitral leaflet

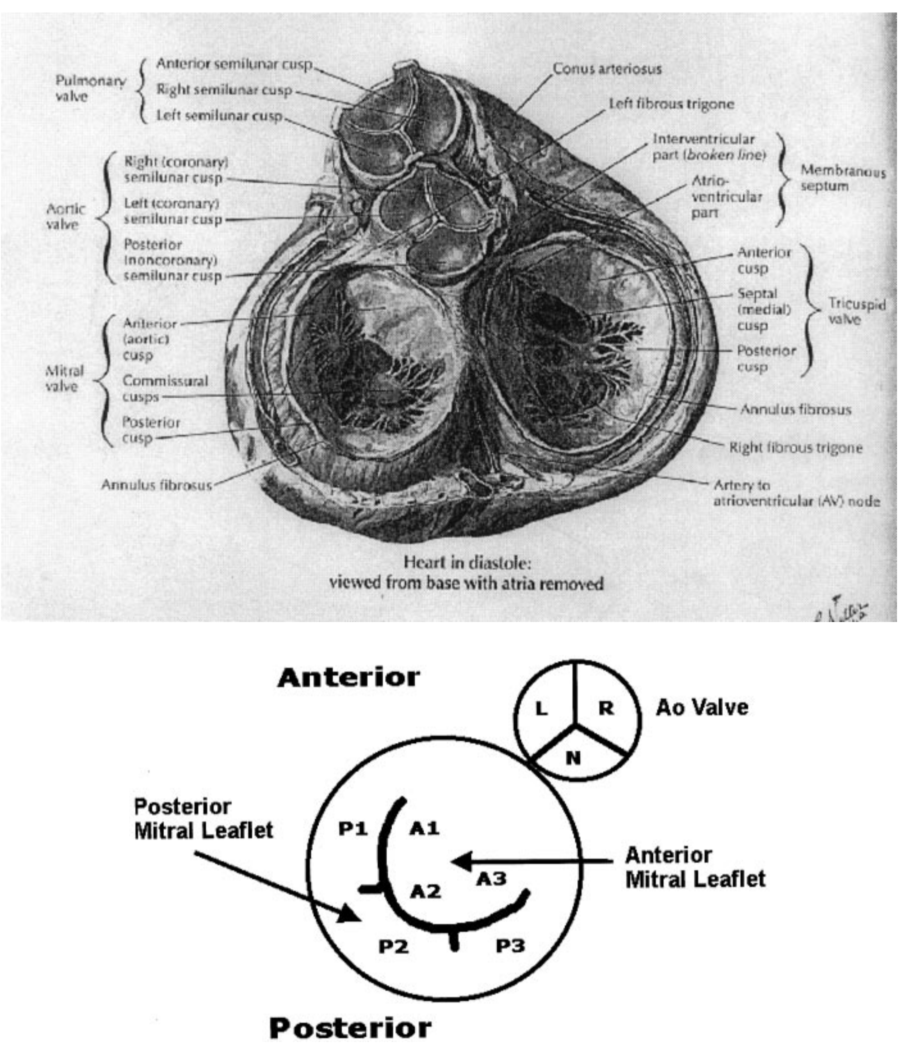
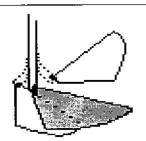
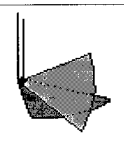
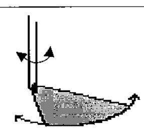


Figure 1. Top, A cross-sectional drawing of the heart at the level of the atrioventricular valves, showing the mitral valve and its relationship with the aortic and tricuspid valves (reproduced with permission from the *Atlas of Human Anatomy* by Frank Netter, MD). Bottom, A drawing demonstrating the Carpentier nomenclature of the mitral valve. The valve is divided into two leaflets: posterior and anterior. The posterior leaflet is further divided into three scallops: P1, P2, and P3. P1 is adjacent to the anterolateral commissure, near the left atrial appendage. P3 is adjacent to the posteromedial commissure. The anterior leaflet is also divided into three segments: A1, A2, and A3, located opposite the corresponding scallops of the posterior leaflet. In the classic anatomic nomenclature, P1 corresponds to the anterolateral scallop, P2 to the middle scallop, and P3 to the posteromedial scallop of the posterior mitral leaflet. A1, A2, and A3 correspond to the anterolateral, middle, and posteromedial areas of the anterior mitral leaflet, respectively. The mitral valve is seen from the atrium, a view similar to the surgeon's perspective; that is, the patient's left side is on the left and the patient's right side is on the right. To obtain the standard transesophageal echocardiography views shown in Figure 3, the image must be rotated 180° so that the patient's left is on the right side of the screen and the patient's right is on the left side of the screen.

Table 1. Definition of Terms

Anteflexion / Retroflexion of the Probe		Movement of the tip of the probe in the antero-posterior diameter, obtained by moving the large wheel on the probe. Anteflexion moves the scanning plane "cephalad" and retroflexion moves the plane "caudad".
Rotation of the transducer (motor)		Movement of the scanning elements of the probe (and the scanning plane) around an axis perpendicular to the shaft of the probe. Expressed in degrees on the video screen and adjusted by pressing a control on the handle of the TEE probe.
Rotation of the shaft of the probe		Movement of the probe around its long axis, obtained by "twisting" the shaft of the probe to the right (clockwise) or to the left (counterclockwise). This moves the scanning plane to the right or left of the patient.

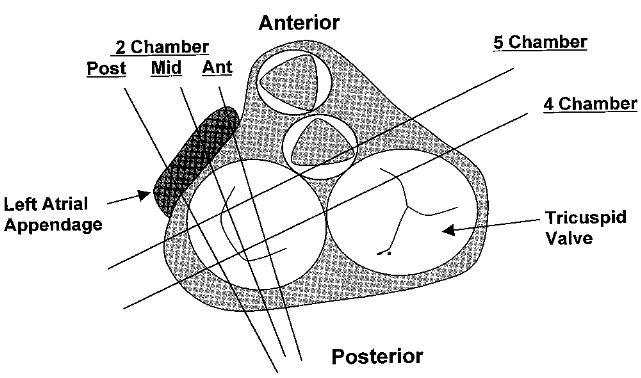


Figure 2. A schematic drawing of the same section of the heart as Figure 1, through the plane of the atrioventricular valves. It depicts the planes of the different cross-sections of the systematic examination. The plane of the short axis is parallel to the page and cannot be demonstrated. Again, the image must be rotated 180° to obtain the same orientation as the standard transesophageal echocardiography planes shown in Figure 3.

only (part of the left ventricular outflow tract can also be seen in this plane). Then, by slowly turning the shaft of the probe counterclockwise, the scan is moved across the valve from the patient's right to the patient's left, stopping at three distinct cross sections: the two-chamber anterior cross-section, which shows a large anterior leaflet and a small posterior leaflet; then the two-chamber mid cross-section, in which two coaptation points can be seen; and the two-chamber posterior cross-section, in which the plane of the scan is posterior to the coaptation line of the valve (Figure 3). This sequence of cross-sections ensures visualization of all the mitral segments. Finally, the transducer is returned to 0° and the probe is advanced into the stomach until the short-axis cross-section of the mitral valve is obtained (Figure 3). Some anteflexion of the probe is often required to maintain contact with the surface of the stomach. The mitral valve then appears as a semilunar opening with a large anterior and small posterior leaflet (Figure 3). This view is most useful with color Doppler, and it provides additional information on the location of the origin of the regurgitant jet.

Color Doppler is applied over the mitral valve once in the transverse plane, once in the longitudinal plane, and once in the short axis to demonstrate the maximal dimensions and direction of the mitral regurgitant jet.

After approval by our institution's committee on human research, we used this systematic examination prospectively in 13 consecutive patients undergoing native mitral valve surgery for severe mitral regurgitation. These patients were all scheduled for mitral valve repair and possible replacement. We compared the results with those obtained in 11 retrospective controls, consisting of the last 11 mitral valve surgeries (repair, possible replacement) performed for severe MR at our institution before the beginning of the study, a period in which equipment and staffing were comparable to the prospective study. Patients undergoing repeat mitral valve surgery or surgery on a prosthetic mitral valve were excluded from the study.

After induction of anesthesia and tracheal intubation, an investigator blinded to all clinical information about the patient performed the systematic TEE examination of the mitral valve described above and recorded the detailed findings. Each mitral segment was examined, and the precise location and mechanism of MR was identified. After our examination, all TEE findings were shared with the surgeons and anesthesiologists.

After surgery, a second blinded examiner reviewed the recordings and reported each segment of the mitral valve as normal, restricted, prolapsed, or perforated, according to the criteria listed in Table 2. These criteria are a modification of those used by Stewart et al. (9). Annular dilation was also noted, if present.

In the retrospective group, all examinations were also performed by anesthesiologists experienced in TEE, using equipment similar to the prospective study. Before performing their TEE examinations, those anesthesiologists were unlikely to have been aware of the precise location and mechanism of the MR lesions (because preoperative patient records usually mention severe MR but rarely describe the precise location and mechanism of regurgitation). However, it is impossible to be certain of that fact from retrospective data. These examinations included four- or five-chamber and two-chamber cross-sections with and without color Doppler, but no uniformly adopted approach was followed.

Equipment used during the prospective part of the study consisted of Acuson Sequoia and Acuson Aspen systems with V5M adult multiplane probes (Acuson, Mountain View, CA). The retrospective examinations were performed with either an Acuson Aspen system with V5M adult multiplane probe or with an HP

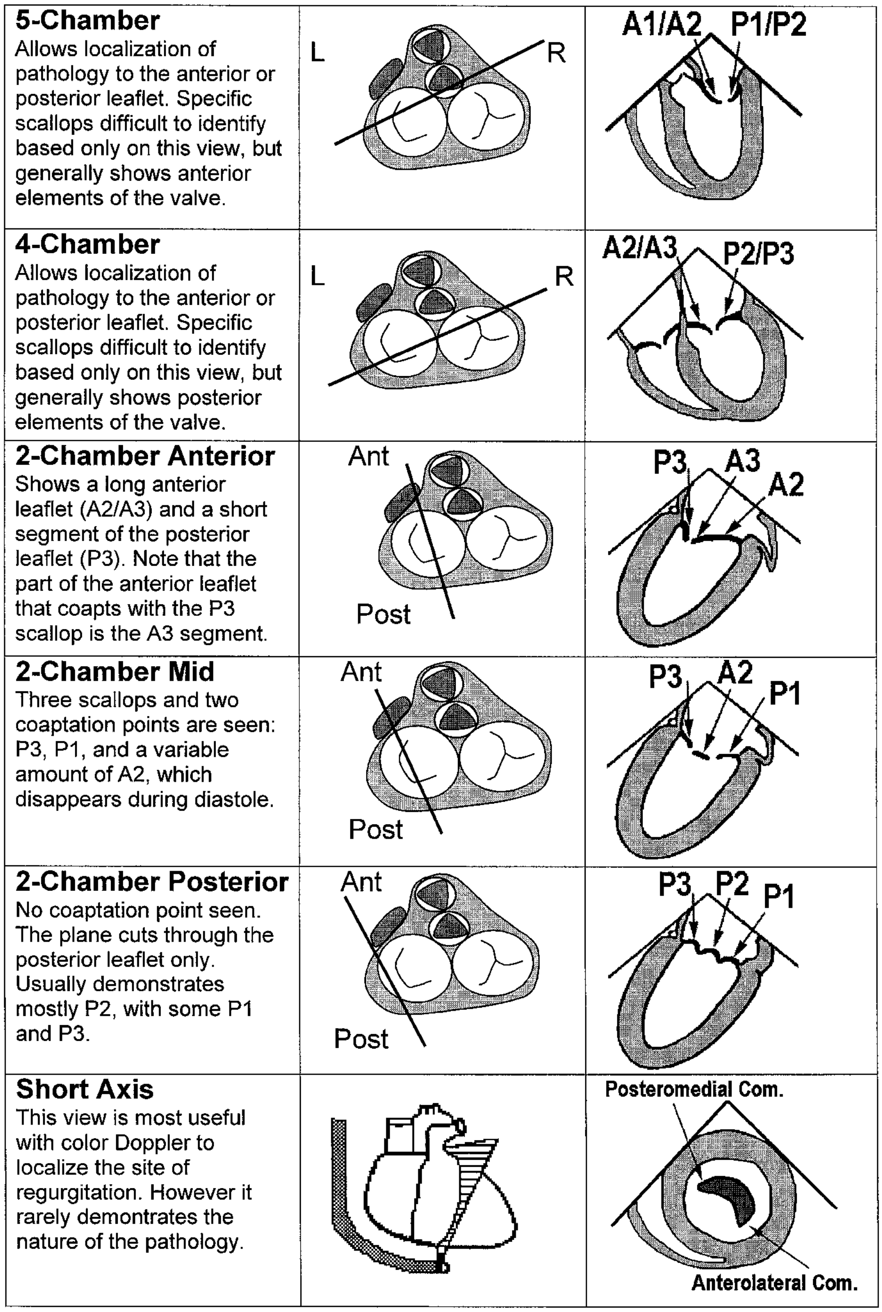


Figure 3. Systematic mitral valve examination. This figure summarizes our systematic examination of the mitral valve. The middle column shows the planes of the different cross-sections. The right column shows the valve segments seen in each view.

Sonos-OR system with adult omniplane probe (Hewlett Packard, Andover, MA).

During surgery, the mitral valve was inspected by the surgeon, and the findings were recorded according to the Carpentier nomenclature, described previously. The same nomenclature was also used in all the surgical reports of the retrospective group.

We obtained the surgical findings from the operative reports for both the prospective and retrospective groups of patients. The surgical diagnosis was assumed to be correct in all cases.

Based on the premise that the major determinants of the surgical approach are the mechanism of regurgitation, the affected mitral leaflet, and the presence or absence of commissural involvement, we defined TEE errors as major or minor. Table 3 describes our classification. This classification is arbitrary, but it helped us to evaluate the clinical importance of our diagnostic errors. We then compared the prospective and retrospective TEE results with the surgical findings in terms of each mitral segment, overall diagnostic accuracy, and rate of major and minor errors.

Table 2. Mechanisms of Mitral Regurgitation (MR)

Mechanism	Description
Severe prolapse	Part of the scallop or the entire scallop moves above the mitral annulus during systole. The MR jet is eccentric and directed away from the diseased scallop.
Restricted leaflet	Decreased motion of a leaflet or scallop associated with chordal shortening. The MR jet may be central if the whole valve is restricted, or eccentric if the leaflets are affected to different degrees. Usually, the jet is directed toward the restricted leaflet.
Annular dilation	The leaflets are structurally normal, but there is failure of coaptation due to stretching of the mitral annulus. The MR jet is usually central.
Perforated leaflet	Self-explanatory. MR jet variable and often eccentric, depending on the size and location of the perforation.
Vegetation	Self-explanatory. MR jet variable depending on the location and extent of the lesion.

The χ^2 test was used to establish statistical significance of the results with α and β set at 0.05 and 0.2, respectively. κ analysis was used to assess the reproducibility of interpretations between the two TEE observers. In the case of disagreement, a consensus was reached, and this consensus was compared with the independent evaluation of a third expert reviewer. If consensus could not be reached or if the third expert failed to confirm the consensus, the recording was deemed uninterpretable.

Results

The prospective group consisted of 13 patients with 78 mitral valve segments. The retrospective controls included 11 patients with 66 mitral segments. One patient (Retrospective Patient 3) was excluded from the analysis because the reviewers could not agree on the TEE diagnosis. The patient had a dilated ventricle with poor contractile function, and a consensus could not be reached on whether the leaflet motion was restricted or whether the MR was purely the result of annular dilation. The remaining control group consisted of 10 patients with 60 mitral valve segments. The age, gender, and incidence of other valvular lesions or other cardiac diseases were not significantly different between the two groups. All patients had moderately severe or severe MR.

In the prospective group, the systematic mitral valve approach diagnosed the correct mechanism of regurgitation and the precise location of the pathology in 12 of 13 patients (92%). In the remaining patient, the TEE revealed severe prolapse of the P2 and P3 segments, whereas the surgeon found prolapse of the P2 segment only, which, according to our classification, represents a minor error (wrongly diagnosed an extension of the lesion to a noncommissural area on the same leaflet) (Table 3). In the retrospective group, TEE made the correct diagnosis in only 6 of 10 patients (60%). In the remaining four patients, the TEE errors were as follows: in two cases, the wrong mechanism of MR was diagnosed (in Patient 5, TEE diagnosed posterior leaflet restriction, whereas the surgeon found anterior leaflet prolapse; in Patient 7, TEE diagnosed restricted leaflet motion and annular dilation, but the surgeon found normal leaflets and only a dilated annulus). In the other two patients (Patients 1 and 9), TEE diagnosed a posterior leaflet prolapse but misdiagnosed additional prolapse of the anterior leaflet. These were all major errors according to our classification (wrong mechanism of MR or missing pathology on the other mitral leaflet). Table 4 presents each patient's data in detail.

In the segment by segment analysis, the systematic TEE examination visualized and correctly diagnosed 75 of 78 (96%) mitral valve segments in the prospective group as being normal or abnormal. In the retrospective group, only 42 of 60 (70%) mitral segments were visualized and correctly diagnosed. This difference was statistically significant ($P < 0.001$).

Interrater agreement was strong, with a κ value of 0.82 ($P < 0.001$). There were no disagreements between reviewers on the TEE diagnosis in the 13 patients of the prospective group. The reviewers did not agree on the TEE diagnosis in 3 of the 11 patients in the retrospective control group. Consensus agreement was reached in two of the three, and the last patient (Retrospective Patient 3) was excluded from the final analysis, as discussed above.

Discussion

We designed this study in response to the expressed need of our cardiac surgeons to obtain more information about the precise location of mitral valve lesions before cardiopulmonary bypass. We have adopted this systematic examination as our clinical standard because it clearly improved our assessment of the mitral valve segments, and it reduced our incidence of diagnostic errors, which could theoretically affect patient outcome. In addition, the new examination produced recordings that were more reproducibly interpreted than the recordings produced during the retrospective period, although the same experts reviewed all the recordings.

Table 3. Criteria for Classification of Transesophageal Echocardiography Errors

Major errors	Minor errors
The diagnosed mechanism of regurgitation is wrong.	The diseased scallop is identified, but extension of the lesion to a noncommissural area is missed.
The lesion is diagnosed on the wrong leaflet.	The diseased scallop is identified, but extension to an adjacent scallop is diagnosed when, in fact, there is none.
A commissural lesion, or the extension of a lesion to a commissural area, is missed.	

Table 4. Detailed Results

	Surgical diagnosis of mitral valve pathology	TEE diagnosis	Difference	Outcome
Systematic mitral valve examination				
Patient				
1	Severe prolapse A2 and A3	Same	None	Repair
2	Severe prolapse P2	Same	None	Repair
3	Severe prolapse P2	Severe prolapse P2 and P3	Minor	Repair
4	Destruction of A3 and P3 by vegetation	Same	None	Replacement
5	Severe prolapse P1	Same	None	Repair
6	Severe prolapse P3	Same	None	Repair
7	Severe prolapse P1 and P2	Same	None	Repair
8	Restricted posterior leaflet, severe prolapse A2	Same	None	Replacement
9	Severe prolapse A2	Same	None	Replacement
10	Severe prolapse A2	Same	None	Repair
11	Severe prolapse P3	Same	None	Replacement
12	Severe prolapse P3	Same	None	Repair
13	Severe prolapse P2	Same	None	Repair
Retrospective controls				
Patient				
1	Severe prolapse P2, A2, and A3	Severe prolapse P2 and P1	Major	Repair
2	Restricted anterior and posterior leaflets	Same	None	Replacement
3	Restricted A1 and A2 and chordal shortening	Examiners could not agree (see text)	—	Repair
4	Restricted anterior and posterior leaflets	Same	None	Replacement
5	Severe prolapse A2	Restricted posterior leaflet	Major	Repair
6	Severe prolapse P2 and P3	Same	None	Repair
7	Annular dilation	Restricted anterior and posterior leaflets and annular dilation	Major	Repair
8	Perforated aneurysm A1 and A2	Same	None	Repair
9	Severe prolapse P2, A1, A2, and A3	Severe prolapse P2	Major	Repair
10	Restricted anterior and posterior leaflets	Same	None	Replacement
11	Severe prolapse A3 and P3	Same	None	Repair

TEE = transesophageal echocardiography.

Our study population included different mechanisms of MR, the most common of which was severe leaflet prolapse. This is a common cause of isolated MR in the general population, and the numbers in the prospective group suggest that our approach works very well in patients with severe leaflet prolapse.

Extensive discussion has been devoted to the determination of the severity of MR, but little has been written on the precise localization of MR, and many of the major textbooks do not provide much guidance on the subject (10–12).

Stewart et al. (9) reported an 85% accuracy of intraoperative TEE in diagnosing the mechanism of MR in 286 surgical patients. Their study, using mainly leaflet motion and jet direction, investigated the mechanism of regurgitation and involvement of the whole mitral apparatus but did not attempt to localize lesions to specific mitral valve segments.

Our approach complements their results and suggests that a similar or even greater overall diagnostic accuracy can be maintained while allowing precise localization of lesions to specific mitral valve segments.

Foster et al. (13) recently published an approach to the TEE evaluation of the mitral valve based on the Carpentier nomenclature and reported an accuracy identical to ours (96%) in identifying diseased segments. They applied their method retrospectively to previously recorded mitral valve examinations and therefore could not identify the value of a systematic examination itself. Their study was a systematic review of recordings, not a systematic examination of the mitral valve, and they did not describe the specific sequence of views that was used at the time that the examinations were recorded. We believe that a systematic acquisition of views is the best way to ensure that all the views are present for an accurate diagnosis.

Our examination stresses the importance of thorough two-dimensional imaging of the valve before applying color Doppler. It also shows that the longitudinal cross-sections are not complementary, but essential in pinpointing lesions to a precise segment of the mitral valve. Because of the variability in cardiac anatomy, intrinsic landmarks in the mitral valve are more consistent than landmarks external to the mitral valve. The nature of the studied population makes this particularly important, as most patients with severe MR have enlarged and distorted cardiac anatomy. Our solution to this problem was to use an examination sequence based on mitral anatomy, in which each view serves as a reference for the next one, rather than independently defined views based on extravalvular structures.

In this study, we use the Carpentier nomenclature of the mitral valve because it is the one used at our institution. Kumar and Duran (14) proposed a different terminology. Although our systematic examination was only tested using the Carpentier nomenclature, it is likely that it would function well with both classifications. Figure 4 depicts the two nomenclatures.

Our study is limited by its small number of patients. The size of the retrospective control group was limited by the volume of mitral surgery at our institution during the period when comparable TEE equipment and staffing were available. We chose to end the prospective part of the study once we thought that the usefulness of the technique for the identification of the location and mechanism of mitral pathology had been demonstrated. We used retrospective controls rather than a randomized prospective approach. The reason was that once we had developed our systematic approach, we could not perform an unbiased control examination prospectively without applying the new techniques. This study design is also limited by the fact that the examiners in the prospective group knew

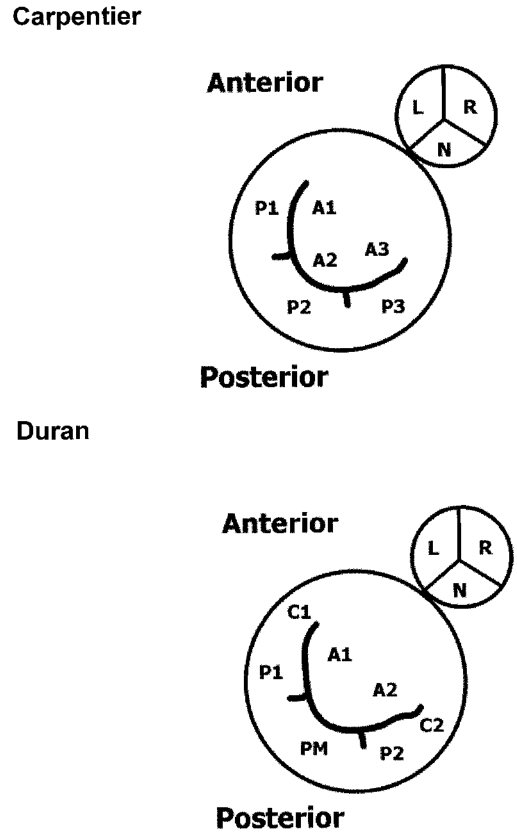


Figure 4. This drawing displays two nomenclatures of the mitral valve used in clinical practice today. Top, The Carpentier nomenclature, as described in Figure 1. Bottom, The nomenclature proposed by Duran: the three scallops of the posterior mitral leaflet are named P1, P2, and PM (middle); the anterior leaflet is divided into two segments, A1 and A2; and the commissural areas are called C1 and C2. In both, the mitral valve is shown with its relationship to the aortic valve.

that they were participating in a study, whereas the examiners in the retrospective group did not. We cannot be certain that the anesthesiologists who performed the studies in the retrospective group were blinded to the diagnoses, but the reviewers who interpreted the studies were blinded to all diagnoses in both the prospective and retrospective limbs of the study. This study design also resulted in groups that were different in the distribution of pathology, and the prospective group did not produce as wide a variety of pathologies. The proportion of patients with leaflet prolapse was greater in the prospective group than in the retrospective group. However, all the errors in the retrospective group, except one, involved patients with severe leaflet prolapse (i.e., cases comparable to the prospective group). Additionally, we showed an improvement in identification of individual mitral segments with this approach, which can help with detection and localization of all types of mitral lesions. Still, the distribution of patients in the prospective group limits the generalizeability of the results beyond patients with severe leaflet prolapse. Finally, the surgeons may have been biased in their interpretation of mitral pathology by our TEE findings, but we could not blind the responsible clinicians from the potentially useful clinical information contained in the results of our examination.

We conclude that this systematic TEE examination of the mitral valve improves our ability to reliably identify mitral valve segments and to precisely localize pathologies, especially in patients with severe mitral leaflet prolapse. It may also improve the diagnosis of the mechanism of MR. Finally, interpretation of this examination is more reproducible than our previous nonstandardized examination.

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