Pre-operative transthoracic real-time three-dimensional echocardiography in patients undergoing mitral valve repair: accuracy in cases with simple vs. complex prolapse lesions

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Aims

The aim of this study, undertaken in patients who underwent mitral valve (MV) repair surgery, was to evaluate the accuracy of pre-operative three-dimensional (3D) transthoracic echocardiography (TTE) in the evaluation of MV pathology in cases with simple or complex lesions.

Methods and results

Two hundred consecutive patients with severe mitral regurgitation due to degenerative MV prolapse underwent a complete 3DTTE the day before surgery. Three-dimensional TTE data were compared with MV surgical inspection. Three-dimensional echocardiography was feasible in a relatively short time (5 ± 3 min) with good (67%) and optimal (21%) imaging quality in the majority of cases. Three-dimensional TTE allowed an accurate identification (95% accuracy) of all MV lesions. Seventy-three (36.5%) patients had simple lesions at 3DTTE and 71 of them (97.2%) underwent a simple surgical procedure; 127 (63.5%) had complex lesions at 3DTTE and, in these cases, surgeons performed either simple procedures (48%) or complex procedures (47.2%) or valve replacement in 4.7% (after a first attempt for repair).

Conclusion

Three-dimensional TTE is feasible, not time-consuming, and accurate in identifying cases with simple vs. complex MV lesions.

Keywords

Three-dimensional transthoracic echocardiography • Mitral valve prolapse • Transoesophageal • Echocardiography • Cardiac surgery

Introduction

Since the 1970s, mitral valve (MV) repair has become preferential to replacement1–3 and is now used in the overwhelming majority of patients with MV prolapse. Recent guidelines have underlined the importance of early surgical intervention to preserve long-term left ventricular function in severe MR.4–8 In this regard, a non-invasive pre-operative assessment of MV anatomy is essential to define feasibility and complexity of repair.9 Three-dimensional (3D) echocardiography is a new emerging technique that allows a very precise localization of MV prolapse.10–18 Recent data showed that 3D echocardiography is superior in comparison with the corresponding 2D techniques in the description of MV pathology. In particular, since real-time 3D transthoracic echocardiography (3DTTE) has an accuracy similar to that of 2D transoesophageal echocardiography (TOE),19–24 this new technique may be integrated in the standard 2D examination and should be regarded as an important tool in the decision process of MV repair.

The aim of this prospective study was three-fold: (i) to evaluate the accuracy of real-time 3DTTE (vs. surgical inspection) in a large
consecutive cases undergoing MV repair in the recognition and localization of all components of the MV leaflets; (ii) to compare the accuracy of this 3DTTE in cases with simple or complex lesions; (iii) to correlate 3D results to surgical procedures.

Methods

Patient population
Two hundred consecutive patients (mean age 60.9 ± 12; range 26–83; 132 males/68 females) with severe MV regurgitation due to degenerative MV prolapse were enrolled in the study. They were all suitable for surgical MV repair. Exclusion criteria were associated MV stenosis, previous endocarditis, history of coronary artery disease, and chronic atrial fibrillation.

Study protocol
All patients underwent a complete 2D and 3DTTE the day before MV surgery. Immediately before surgery in the operating room, a complete 2DTOE examination was performed. In the last 50 out of 200 cases, 3DTOE was also performed. Three-dimensional TTE data were compared with 2DTOE data (and with 3DTOE in the last 50 cases) and with surgical inspection of the MV performed by the operating surgeon (M.Z., F.A.). Surgical techniques were annotated in details immediately after surgery. The local ethics committee approved the study. Informed consent was obtained from all patients.

Transthoracic 2D and 3D echocardiography
A complete TTE study was performed in all patients using a Sonos 7500 or IE33 ultrasound units and a S3 or SS-1 sector array probes (Philips Medical Systems, Andover, MA, USA). Real-time 3DTTE was performed at the end of the 2D examination with the same ultrasound units by utilizing an X4 or X3-1 probes. The protocol included real-time parasternal views including 3D zoom technology that allowed a more focused visualization of the entire MV. ‘Full volume’ analysis was also performed in all cases from the apical view. MV was visualized from the atrial point of view, in the so-called surgical view.19 The Carpentier nomenclature was applied to the MV leaflets. Each scallop of posterior leaflet was defined through the indentations (or clefts when present) which anatomically divided its lateral (P1), central (P2), and medial (P3) sections. The anterior leaflet scallops facing the posterior ones were classified as A1, A2, and A3. The antero-lateral (AL) and postero-medial (PM) commissures were also evaluated. All segments were classified as normal, prolapsing (>2 mm beyond the annulus plane in 2DTEE and as a bright convexity of bulge in 3D), and flail. The presence of ruptured chordae was also annotated. Three-dimensional acquisition and reconstruction times were measured in each patient.

Prolapse lesions were defined as simple or complex. Simple anatomical lesions included isolated P2 prolapse or P3 associated with P1 or P3. All other lesions including lesions involving the entire posterior leaflet, lesions of the anterior leaflet, bileaflet prolapse, and commissural lesions were defined as complex. This definition was based on the literature data suggesting that simple lesions are generally treated surgically with simple techniques, while lesions defined as complex may require more complex procedural approaches.25–27

Transoesophageal 2D and 3D echocardiography
Two-dimensional TOE was performed intra-operatively in all patients after induction of anaesthesia; in the first 150 cases, a 5 MHz multipurpose probe (Philips, model 21354A plus a Philips echocardiography system, model Sonos 5500, Andover, MA, USA) was utilized, whereas in the last 50 cases a 3DTOE multiplane probe (Philips, model Omni III plus a Philips echocardiography system, model iE33, Andover, MA, USA) was used. Multipane 2DTOE evaluation included a complete standard protocol for the evaluation of the MV1–3 allowing a complete description of all segments of the valve. In cases with 3DTOE acquisitions, 3D live and real-time zoom images of the MV were acquired and images of the MV were obtained from the atrial perspective (surgical view) and analysed with the same protocol used for 3DTTE.

Imaging analysis and intra- and inter-observer variability
All 3DTTE images were analysed by two experts in 3D echocardiography (M.P., G.T.), blinded to the surgical findings. Two-dimensional TOE and 3DTOE were performed and analysed before surgical inspection by a cardiologist (M.M.) and two anaesthesiologists expert in 2DTOE and 3DTOE (L.S., E.S.). Three-dimensional TTE images were analysed in a random sequence. The quality of 3D images, judged on the basis of the resolution of MV anatomy, and on the presence or absence of artefacts throughout the cardiac cycle was rated as optimal, good, sufficient, and insufficient. In 30 randomly selected data sets, two of the authors (A.M., C.A.G.) reviewed 3DTTE, identified, and annotated all anatomical details. One of the authors re-reviewed the 3D images 1 month later to assess intra-observer variability.

Surgical inspection and validation
The surgeon described the anatomy of the valve using the same Carpentier classification. He was aware of the 2DTOE findings, but not of the 3D analysis.

Surgical techniques
Table 1 reports main surgical techniques utilized in our series. Surgical procedures were arbitrary divided in simple vs. complex techniques according to the literature data.25–28 Personal experience, and data published on complex techniques that may lead to less durable results on mitral competence.

Statistical analysis
The sensitivity and specificity of echocardiographic evaluation of the involved scallops (or chordal rupture) was calculated with surgical findings as a reference. Accuracy between the method and surgery was defined as the sum of true positive and true negative results divided by the number of scallops (or prolapsed valves). Inter- and intra-observer correlation were made using Pearson coefficient. We compared categorical variables by using the Chi-square test (with continuity correction for small numbers). A value of P < 0.05 was considered to be significant.

Results
Three-dimensional TTE was obtained in all patients. The time to obtain and analyse the 3DTTE images was 5 ± 3 min. Quality of 3DTTE was insufficient in 4% cases, sufficient in 8%, good in 67%, and optimal in 21% cases. Major reasons for insufficient quality were suboptimal echocardiographic windows, minimal patient movements, respiration, and cardiac arrhythmia. However, anatomic visualization of the MV during end-systolic
frames allowed diagnostic information also in cases with suboptimal quality and therefore all patients were included in the study.

At surgical inspection (Table 2), approximately one-third of the patients had isolated P2 lesions (31%), while the majority had more complex pathologies. AL and PM commissures were involved in 4.5 and 14.5% of the cases, respectively. Sensitivity, specificity, and accuracy of the 3DTTE and 2DTOE echocardiographic methods for each of the segmental lesions and for chordal rupture are reported in Table 3. Overall accuracy and specificity of the 3DTTE were high in all segments. Accuracy in prolapse detection in AL and PM scallops was significantly higher for 3DTTE in comparison with 2DTOE. Sensitivity of 3DTTE was slightly lower in AL commissure, P1, and A1. Despite a significant slightly lower value of specificity in complex vs. simple lesions (93 vs. 99%, respectively), sensitivity was similar (92 vs. 93%) and overall accuracy was high in complex and simple lesions (93 vs. 98%).

In the 50 patients in which 3DTOE was also applied, sensitivity (93%), specificity (98%), and overall accuracy (97%) of 3DTOE were superior ($P<0.01$) to both 3DTTE (92.5, 97, and 95.5%, respectively) and 2DTOE (88, 96, and 95%, respectively).

There was a close agreement in recognition scores both between the two different observers (inter-observer variability: 3DTTE: $r=0.78$, $P<0.001$), and between the repeated measurement of the first observer (intra-observer variability: 3DTTE: $r=0.88$ $P<0.001$). Figure 1 shows examples of cases with simple and complex prolapses correctly identified by 3DTTE. Figure 2 shows comparisons between pre-operative 3DTTE and intra-operative anatomical surgical findings cases with simple and complex prolapses.

As concerns surgical techniques (Table 1), quadrangular resection, either as an isolated procedure or in combination with other techniques (199/200 ring anuloplasty, 38% sliding technique, 36% posterior annular plication, 36% Papillary muscle repositioning, 36% edge-to-edge technique) was the most common technique, followed by posterior leaflet folding (30%), and posterior leaflet sliding (38%).

### Table 1
Percentage of the different simple or complex surgical techniques for mitral valve repair in the entire population

<table>
<thead>
<tr>
<th>Simple surgical techniques</th>
<th>Complex surgical techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadrangular resection of posterior leaflet</td>
<td>Replacement of chordae tendinae with Gore-Tex neo-chordae</td>
</tr>
<tr>
<td>Posterior annular plication</td>
<td>Transfer of chordae tendinae on anterior leaflet and one or more technique(s) for simple case(s)</td>
</tr>
<tr>
<td>Slinging posterior leaflet on posterior leaflet</td>
<td>Papillary muscle repositioning and one or more technique(s) for simple case(s)</td>
</tr>
<tr>
<td>Annuloplasty</td>
<td>Edge-to-edge technique and one or more technique(s) for simple case(s)</td>
</tr>
</tbody>
</table>

### Table 2
Mitrval valve pathology by surgical inspection of the study population

<table>
<thead>
<tr>
<th>Lesion</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated posterior leaflet</td>
<td>112 (56%)</td>
</tr>
<tr>
<td>Isolated P1</td>
<td>4 (2%)</td>
</tr>
<tr>
<td>Isolated P2</td>
<td>62 (31%)</td>
</tr>
<tr>
<td>Isolated P3</td>
<td>4 (2%)</td>
</tr>
<tr>
<td>Posterior leaflet &gt;1 scallop</td>
<td>42 (21%)</td>
</tr>
<tr>
<td>Isolated anterior leaflet</td>
<td>26 (13%)</td>
</tr>
<tr>
<td>Isolated A1</td>
<td>5 (2.5%)</td>
</tr>
<tr>
<td>Isolated A2</td>
<td>7 (3.5%)</td>
</tr>
<tr>
<td>Isolated A3</td>
<td>2 (1%)</td>
</tr>
<tr>
<td>Anterior leaflet &gt;1 scallop</td>
<td>16 (8%)</td>
</tr>
<tr>
<td>Anterior and Posterior leaflet</td>
<td>62 (31%)</td>
</tr>
<tr>
<td>Associated lesions</td>
<td></td>
</tr>
<tr>
<td>Anterolateral commissure</td>
<td>9 (4.5%)</td>
</tr>
<tr>
<td>Postero-medial commissure</td>
<td>29 (14.5%)</td>
</tr>
<tr>
<td>Chordal rupture</td>
<td>132 (66%)</td>
</tr>
</tbody>
</table>

P1, lateral scallop of the posterior leaflet; P2, middle scallop of the posterior leaflet; P3, medial scallop of the posterior leaflet; A1, lateral scallop of the anterior leaflet; A2, middle scallop of the anterior leaflet; A3, medial scallop of the anterior leaflet.
Real-time 3DTTE in patients undergoing MV repair

Table 3 Detection of pathology with transthoracic three-dimensional and transoesophageal two-dimensional echocardiography

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
<th>Accuracy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3DTTE</td>
<td>2DTOE</td>
<td>3DTTE</td>
</tr>
<tr>
<td>Posterior leaflet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>70</td>
<td>70</td>
<td>98</td>
</tr>
<tr>
<td>P2</td>
<td>99a</td>
<td>98.2a</td>
<td>89a</td>
</tr>
<tr>
<td>P3</td>
<td>89a+1</td>
<td>83+1c</td>
<td>95</td>
</tr>
<tr>
<td>Posterior leaflet &gt;1 scallop</td>
<td>92</td>
<td>85c</td>
<td>96</td>
</tr>
<tr>
<td>Anterior leaflet</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A1</td>
<td>73</td>
<td>69</td>
<td>100</td>
</tr>
<tr>
<td>A2</td>
<td>100f</td>
<td>94f</td>
<td>91f</td>
</tr>
<tr>
<td>A3</td>
<td>92f</td>
<td>89f</td>
<td>100f</td>
</tr>
<tr>
<td>Anterior leaflet &gt;1 scallop</td>
<td>92</td>
<td>85c</td>
<td>97</td>
</tr>
<tr>
<td>Anterolateral commissure</td>
<td>71</td>
<td>70</td>
<td>99</td>
</tr>
<tr>
<td>Postero-medial commissure</td>
<td>89.5*</td>
<td>85a</td>
<td>96</td>
</tr>
<tr>
<td>Chordal rupture</td>
<td>95</td>
<td>98c</td>
<td>90</td>
</tr>
<tr>
<td>Overall accuracy</td>
<td>92.5</td>
<td>85c</td>
<td>96</td>
</tr>
</tbody>
</table>

P1, lateral scallop of the posterior leaflet; P2, middle scallop of the posterior leaflet; P3, medial scallop of the posterior leaflet; A1, lateral scallop of the anterior leaflet; A2, middle scallop of the anterior leaflet; A3, medial scallop of the anterior leaflet.

*P < 0.05 2DTOE vs. 3DTTE.
†P < 0.05 vs. P1.
‡P < 0.05 vs. P2.
§P < 0.05 vs. A1.
‖P < 0.05 vs. A2.
¶P < 0.05 vs. anterolateral commissure.

and 36% posterior annular plication), was the most common intervention. Figure 3 is a flow-chart which describes types and results of surgery depending on the complexity of the 3DTTE lesions. Seventy-three patients (36.5%) out of 200 had simple lesions at 3DTTE examination. In these cases, simple techniques were utilized in 71 patients (97.2%) while only in two cases a complex procedure was performed. No patient in this group underwent MV replacement. One hundred and twenty-seven cases (63.5%) had 3DTTE lesions classified as complex. In these cases, surgeons performed simple surgical procedures in 61 (48%), complex procedures in 60 (47.2%), and in the remaining 6 cases (4.7%), MV replacement was necessary after the first repair attempt.

**Discussion**

In the present study, we demonstrated that real-time 3DTTE has a very high accuracy in the evaluation of MV morphology in patients with MV prolapse undergoing surgical repair, and furthermore this method allowed to discriminate simple vs. complex lesions and to facilitate the prediction of surgical procedures. In this large series of patients, we confirmed and extended previous data from our group demonstrating that 3DTTE may be routinely used providing a detailed anatomic depiction of the MV in a relatively short time. Besides overall accuracy of 3DTTE is highest to every other echocardiographic techniques, 3DTTE accuracy is similar to 2DTOE (central scallops) or slightly superior (lateral and medial scallops) than 2DTOE.

New generation 3D technology reduces the acquisition and reconstruction time to few minutes and facilitates the visualization of the MV. In the majority of cases (88%), imaging quality was good or optimal. We found a 95% overall accuracy by 3DTTE for the identification of MV pathology in this unselected population of 200 cases undergoing MV repair, a percentage comparable to previous studies and similar to previous data concerning 2DTOE. Interestingly, in our patients, 3DTTE was not different to 2DTOE in the identification of P2 and A2 involvement, but was significantly superior in the evaluation of PM and AL segments. Therefore, this study confirms recent data showing that real-time 3DTTE may be integrated in the standard 2D examination facilitating the exact spatial localization of pathological structures and avoiding the need for mental reconstruction of 3D valve anatomy by the examiner. Moreover, to our knowledge, this is the first article which demonstrates the predictive value of 3DTTE in the identification of simple vs. complex cases of MV prolapse. In this contest, the role of TTE is particularly important not only in patients in whom the surgical indication is obvious, but also in the follow-up of patients without surgical indication in whom serial examinations are very useful to determine the correct surgical timing. In these cases, a complete 2D and 3DTTE examination may reduce the need for a TOE approach. Monin et al. showed that 2DTTE has a high accuracy in the precise localization or prolapsed or flailed segments. However, accuracy for complex lesions was less satisfying (60%) than in P2 lesions (95%). In this regard, our data further reinforce the concept that 3DTTE should be...
regarded as an important adjunct to standard transthoracic 2D examination in decision regarding MV repair. Our study population was in fact characterized by a large percentage of complex MV disease, while isolated P2 prolapse was present in approximately one-third of the cases. Accuracy of the method was high not only in P2 prolapse (97.5%), but also in posterior scallop prolapse >1 (95%), anterior leaflet >1 (95%), and AL commissure (95%) and PM commissure (94%). Sensitivity of the method was high in all segments with the exception of isolated P1, isolated A1, and AL commissure, probably due to the relatively small number of AL scallops involved in our patients. A less favourable visualization of more anterior segments of MV has been demonstrated both for 3DTTE and 3DTOE methods. The complementary use of 3D colour Doppler acquisitions and of sequential longitudinal sections of the valve may further improve the sensitivity in the detection of scallop involvement.

This study demonstrated that the complexity of MV lesion by 3DTTE correlates to surgical procedures. Recent guidelines not only defined clinical and echocardiographic criteria for MV surgery in severe mitral regurgitation, but also stated that in asymptomatic patients MV repair can be considered when there is a high likelihood of durable MV repair at low risk. Despite excellent survival rate in the majority of reports on MV repair, the durability of a successful MV reconstruction for degenerative MV disease is not constant and this should be taken into account when asymptomatic patients are offered early MV repair. Recurrence or MV regurgitation after MV repair varies significantly in different studies and is related to clinical (younger age) and surgical factors. Chordal shortening, implantation of artificial chordae, no use of ring annuloplasty, partially explains the occurrence of MV regurgitation and the need for a second repair or MV replacement at a mean follow-up of 5 years. These surgical techniques are utilized in complex lesions particularly when the anterior leaflet is involved. Our data showed that the overwhelming majority of patients with simple lesions underwent to a simple surgical technique (97.2%), while patients with complex 3DTTE prolapse could be treated by both simple (48%) or complex (47.2%) successful MV repair and 4.7% MV replacement after a first MV repair procedure, based on intra-operative TOE data showing suboptimal repair) surgical procedures. Thus a 2D and 3DTTE may facilitate the prediction of the complexity of the procedures (including the risk for MV replacement) and may facilitate the clinical decision of the correct timing (early surgery vs. delayed procedures).

**Limitations of the study**

Patients with complex 3DTTE prolapses could be treated by either simple or complex surgical techniques. These results are apparently in contrast with the echocardiographic prediction of type of surgery. Typically in bileaflet prolapse, in the absence of significant anterior chordal pathology, a strategy of posterior leaflet resection and annuloplasty corrects anterior leaflet prolapse and mitral regurgitation, and provides a durable repair without the necessity of additional procedures on the anterior leaflet. All
these surgical techniques depend on surgical strategies and experience of surgeons. Simplification of surgical strategies in complex lesions does not detract much from our results in terms of the role of 3DTTE. In fact, 3DTTE accurately defines complex MV anatomy and identifies the population at higher surgical probability (47.2%) of complex surgical techniques or even valve replacement (4.7%). This may influence the correct timing of surgery as suggested in recent guidelines.7,8 Moreover 97.2% of patients with single lesions were correctly identified by 3DTTE and underwent simple surgical procedure.

Due to the recent introduction of 3DTOE, we performed this technique in only 50 cases. However, accuracy of this method (97%) was similar to other published series.19–23 Despite the higher accuracy of 3DTOE, the accuracy of 3DTTE (95%) further reinforces the importance of this technique in MV pathology.
Conclusions

Real-time 3D TTE is a feasible, not time-consuming, non-invasive useful method in identifying the location of simple and complex lesions in patients with MV prolapse undergoing MV repair. This technique should be regarded as an important adjunct to standard 2D examination in recognizing all the components of MV leaflets and may facilitate the prediction of surgical procedures.

Conflict of interest: none declared.

References

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