Analysis of Procedural Effects of Percutaneous Edge-to-Edge Mitral Valve Repair by 2D and 3D Echocardiography

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Background—Analysis of procedural effects in patients undergoing percutaneous mitral valve repair (PMVR) using the edge-to-edge technique is complex, and common methods to define mitral regurgitation severity based on 2-dimensional (2D) echocardiography are not validated for postprocedural double-orifice mitral valve. This study used 3D transesophageal echocardiography (TEE) to determine the functional and morphological effects of PMVR.

Methods and Results—In 39 high-risk surgical patients with moderate to severe functional mitral valve regurgitation, 3D TEE with and without color Doppler as well as 2D transthoracic and TEE was performed before and after PMVR (MitraClip device). Mitral valve regurgitant volume by color Doppler 3D TEE was determined as the product of vena contracta areas defined by direct planimetry and velocity time integral using continuous-wave Doppler. Regurgitant volume was reduced from 84.1±38.3 mL preintervention to 35.6±25.6 mL postintervention. Patients in whom vena contracta area could be reduced >50% had a smaller preprocedural mitral annulus area compared with patients with ≤50% reduction (11.9±3.9 versus 16.1±8.5 cm², respectively; \( P=0.036 \)) and tended to have a smaller mitral annulus circumference (13.0±2.0 versus 14.8±4.1 cm, respectively; \( P=0.112 \)). At 6 months follow-up, left atrial and left ventricular end-diastolic volumes were significantly more reduced in patients in whom regurgitant vena contracta area was reduced by >50% compared with those with less reduction (−11.4±5.2 versus −4.8±7.7%; \( P=0.005 \), and −11.0±7.2 versus −4.5±9.3%; \( P=0.028 \)). The maximum diastolic mitral valve area decreased from 6.0±2.0 to 2.9±0.9 cm² (\( P<0.0001 \)).

Conclusions—Three dimensional TEE demonstrates significant reduction of regurgitant volume after PMVR. The unique visualization of the mitral valve by 3D TEE allows improved understanding of the morphological and functional changes induced by PMVR. (Circ Cardiovasc Imaging. 2012;5:748-755.)

Key Words: 3-dimensional echocardiography ■ image guided intervention ■ mitral regurgitation transesophageal echocardiography ■ valvular repair

Percutaneous mitral valve repair (PMVR) using the edge-to-edge technique has been shown to be safe and effective for treatment of mitral regurgitation considering specific indications.1–3 Analysis of the morphological and functional effects of PMVR is complex. Two-dimensional (2D) echocardiography provides only limited access to morphological changes induced by mitral valve repair, and commonly used techniques based on 2D echocardiography to evaluate functional changes of the mitral valve are not validated for postprocedure double-orifice mitral valve.4 By contrast, 3D echocardiography provides improved visualization of the complex mitral valve morphology. It has been shown to allow accurate analysis of mitral regurgitation severity based on direct measurement of regurgitant orifice areas in 3D images with or without color Doppler.5–9

This study evaluated the morphological and functional changes of the mitral valve induced by percutaneous edge-to-edge repair using 3D transesophageal echocardiography (TEE),2 preprocedural morphological characteristics determined by 3D TEE with impact on functional effectiveness of PMVR,3 changes of the left atrial and left ventricular (LV) volumes at 6 months follow-up related to PMVR effectiveness.

Methods

Patients
In 39 consecutive high-risk surgical patients with moderate to severe mitral valve regurgitation (age 73±9 years; 24 male) and LV ejection fraction of 46±16%, 2D transthoracic echocardiography (TEE), 2D and 3D TEE with and without color Doppler were performed within 24 hours before and after PMVR using the MitraClip device (Abbott Vascular Structural Heart, Menlo Park, CA). Only patients with functional mitral regurgitation and at most trace aortic regurgitation

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Table 1. Patient Characteristics

<table>
<thead>
<tr>
<th>Age, y</th>
<th>73±9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male/female</td>
<td>24 (62%)/15 (38%)</td>
</tr>
<tr>
<td>Logistic Euroscore, %</td>
<td>18±12</td>
</tr>
<tr>
<td>NYHA*</td>
<td>5/18 (46%)</td>
</tr>
<tr>
<td>III</td>
<td>27 (99%)</td>
</tr>
<tr>
<td>IV</td>
<td>21 (71%)</td>
</tr>
<tr>
<td>Ejection fraction, %</td>
<td>46±16</td>
</tr>
<tr>
<td>Coronary artery disease</td>
<td>4 (10%)</td>
</tr>
<tr>
<td>1-vessel</td>
<td>4 (10%)</td>
</tr>
<tr>
<td>2-vessel</td>
<td>4 (10%)</td>
</tr>
<tr>
<td>3-vessel</td>
<td>4 (10%)</td>
</tr>
<tr>
<td>Left atrial area, cm²</td>
<td>29.9±9.9</td>
</tr>
<tr>
<td>Mitral regurgitation grade†</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>VII</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>III</td>
<td>29 (74%)</td>
</tr>
<tr>
<td>IV</td>
<td>10 (26%)</td>
</tr>
<tr>
<td>Color Doppler mitral regurgitation jet area, cm²</td>
<td>7.5±3.2</td>
</tr>
<tr>
<td>Effective regurgitant orifice area by flow convergence method, cm²</td>
<td>0.33±0.15</td>
</tr>
<tr>
<td>Mitral valve area, cm²</td>
<td>6.0±2.0</td>
</tr>
</tbody>
</table>

*New York Heart Association (NYHA) functional classification for the extent of heart failure.
†Mitral regurgitation grade according to Endovascular Valve Edge-to-edge Repair Study (EVEREST) criteria.10

ThreeDimensionalTEEtoAssessMitralValveMorphologyandFunction

MitralsecondaryseveritywasgradedconsideringpreviouslypublishedEndovascularValveEdge-to-EdgeRepairStudy(EVEREST)criteria.10Furthermore,themitralsecondaryjetareawasassessedby2DTEEcolorflowDopplerinanintercommisuralviewusingaNyquistlimitof50to60cm/s,andaolorgainthatjusteliminatedrandomcolorspecklefromnonmovingregions.Accordingly,thesesareaswereassessedseparatelypostinterventionforthetjlocatedmedialandlateraltotheclip.Themedialandthelateralareaswere

summeduptoatotaltjarea.

Figure 1. Three-dimensional TEE full-volume color Doppler view from the anterior root of the left atrium before PMVR (A). A cut plane orthogonal to the regurgitant jet allows direct visualization of the proximal vena contracta area (0.52 cm²) (B). After PMVR a view from the anterior root of the left atrium toward the mitral valve in mid-systole allows assessment of the device effect (C). Orthogonal cut planes of the remaining medial and lateral regurgitation jets can be adjusted allowing direct visualization of the medial (0.16 cm²) (D) and the lateral vena contracta area (0.04 cm²) (E). AL indicates anterolateral; PMVR, percutaneous mitral valve repair; PM, posteromedial; TEE, transesophageal echocardiography; and VCA, vena contracta area.
planes before and after PMVR for each orifice. Medial and lateral areas were summed up to a total MVA after PMVR (Figure 2). Mean diastolic mitral valve pressure gradient (Pmean) was measured by continuous-wave Doppler before and after PMVR for 1 orifice. The impact of MVA preintervention on Pmean postprocedure was evaluated. In patients with atrial fibrillation, measurements of 5 cardiac cycles were averaged.

Clip Position

The commissural line was defined as the line between the posteromedial and the anterolateral edge of the mitral valve in diastole. After PMVR the position of the clip or the 2 clips relative to the center of the commissural line was measured using 3D TEE zoom mode (Figure 3).

Mitral Annulus Dimensions

Before PMVR the mitral valve annulus area, annulus circumference, anterior to posterior diameter, and posteromedial to anterolateral diameter were calculated by analyzing 3D TEE full-volume wide-angle acquisition data sets with a quantification software as previously described13 (Figure 4). The impact of mitral annulus dimensions on the success of PMVR was evaluated. Procedural success was defined as reduction of the total regurgitation VCA >50%.

Analysis of Mitral Valve RV by 2D Echo Techniques

Mitral valve RV was determined by subtracting forward LV outflow from 2D TTE total LV stroke volume as described before4,14. On the basis of 2D TEE, effective regurgitant orifice area (EROA) was calculated using the flow convergence method as previously described. The RV was calculated by multiplying EROA and velocity time integral obtained by continuous-wave Doppler.4 After PMVR, the EROA and RV were calculated separately for the medial and the lateral jet by measuring the radius of each flow convergence zone in the intercommissural view and the peak regurgitant velocity and velocity time integral by continuous-wave Doppler. The medial and lateral regurgitant orifice areas and volumes were summed up to a total EROA and a total RV.
Observer Agreement
In 15 randomly selected studies, 2 observers independently measured the RV by subtracting forward outflow from 2D total LV stroke volume and by 3D TEE direct planimetry of VCA before and after PMVR, and interobserver agreement was assessed by analysis of deviation of each measurements. These same studies were also re-examined by 1 observer at a separate time 1 month later to determine intraobserver agreement.

Statistics
Statistical analysis was performed using the MedCalc software (version 9.5.1.0; Mariakerke, Belgium) and R statistical software (version 2.14.1). Continuous data are presented as mean±SD and are compared with paired Student t test or ANOVA as adequate. Categorical data were presented as frequencies and compared with the Pearson χ2 test. Pearson correlation coefficient (r) was calculated to express agreement between MV A before PMVR and mean diastolic mitral valve gradient postprocedure. Bland-Altman analysis was performed to determine differences in RVs defined by the different analysis methods. Intraclass correlation coefficients (ICCs) were calculated between RVs determined by the different methods. Regression analysis was performed to identify predictors for reduction of VCA >50% after PMVR. Variables included in the analysis were severity of valvular regurgitation, mitral annulus area, mitral annulus circumference, mitral annulus diameters, and use of 1 or 2 mitral valve clips. Receiver-operating characteristics analysis was performed to define the impact of MVA preintervention on mean diastolic pressure gradient postintervention. A P<0.05 was considered significant.

Results
Patient characteristics are given in Table 1. Considering the EVEREST criteria, 29 of the 39 patients had mitral regurgitation grade III and 10 patients had mitral regurgitation grade IV before the procedure. After the procedure, 30 patients had grade I, 8 patients had grade II, and 1 patient had grade III mitral regurgitation. In 28 of the 36 patients alive at 6 months follow-up, the New York Heart Association (NYHA) functional class improved from 3.3±0.5 preintervention to 2.0±0.7 at 6 months follow-up (P=0.0001). Using 3D TEE to assess mitral regurgitant severity before PMVR, VCA was found to be 0.50±0.22 cm2 and RV was 84.1±38.3 mL.

Impact of Edge-to-Edge Repair on Mitral Regurgitation
The remaining medial and lateral regurgitant jet orifice areas after PMVR determined by direct planimetry of VCA using 3D TEE were 0.12±0.10 and 0.09±0.08 cm2, respectively, indicating a reduction of regurgitant area by 58.9% to 36.1% compared with preintervention area. In 15 randomly selected studies, 2 observers independently measured the RV by subtracting forward outflow from 2D total LV stroke volume and by 3D TEE direct planimetry of VCA before and after PMVR. ICC analysis was performed to determine differences in RVs defined by the different analysis methods.15 Intraclass correlation coefficients (ICCs) were calculated between RVs determined by the different methods. Regression analysis was performed to identify predictors for reduction of VCA >50% after PMVR. Variables included in the analysis were severity of valvular regurgitation, mitral annulus area, mitral annulus circumference, mitral annulus diameters, and use of 1 or 2 mitral valve clips. Receiver-operating characteristics analysis was performed to define the impact of MVA preintervention on mean diastolic pressure gradient postintervention. A P<0.05 was considered significant.

Table 2. Mitral Valve Regurgitant Volume Before and After PMVR Determined by Different Methods

<table>
<thead>
<tr>
<th>Regurgitant volume by subtracting LV outflow from 2D TTE LV stroke volume, mL</th>
<th>Before PMVR</th>
<th>After PMVR</th>
<th>Change (%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regurgitant volume by 2D TEE flow convergence method, mL</td>
<td>40.0±16.5</td>
<td>15.3±10.4</td>
<td>−66.4%</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Regurgitant volume by 3D TEE VCA method, mL</td>
<td>56.0±27.4</td>
<td>14.3±10.9</td>
<td>−74.5%</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Regurgitant volume by subtracting LV outflow from 2D TTE LV stroke volume, mL</td>
<td>84.1±38.3</td>
<td>35.6±25.6</td>
<td>−59.2%</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

2D indicates 2-dimensional; 3D, 3-dimensional; LV, left ventricular; PMVR, percutaneous mitral valve repair; TEE, transesophageal echocardiography; and VCA, vena contracta area.

Figure 5. VCA determined by direct planimetry in 3D TEE color Doppler images before PMVR and VCA of the remaining medial and lateral regurgitation jets after PMVR for each patient. 3D indicates 3-dimensional; PMVR, percutaneous mitral valve repair; TEE, transesophageal echocardiography; and VCA, vena contracta area.

VCAtotalpost=0.21±0.13 cm2 (Figure 5). The calculated remaining RV after PMVR by 3D TEE VCA method was 35.6±25.6 mL, indicating a reduction of RV by 59.2%. Patients with improvement in NYHA functional class at 6 months follow-up after PMVR had a greater reduction of VCA compared with patients without improvement in NYHA functional class (−61.1±17.0 versus −47.7±7.9%; P=0.040). There was no significant difference in the reduction of RV between patients with and without improvement in NYHA functional class when 2D TTE-based LV outflow-LV stroke volume method was used (−64.7±19.1 versus −74.8±19.0%; P=0.193) or 2D TEE flow convergence method was applied (−75.5±16.8 versus −70.5±16.1%; P=0.460).

RVs before and immediately after PMVR determined by the different 2D and 3D imaging methods are provided in Table 2. Considering RV analysis based on calculation of 2D TTE LV stroke volume-LV outflow, a reduction of 66.4% was seen postintervention and considering RV analysis based on 2D TEE flow convergence method, a reduction of RV by 74.5% was seen. Difference in means determined by Bland-Altman analysis between RV defined by 3D TEE and 2D TEE was 28.1 mL (95% CI −39.4 to −16.8 mL) before PMVR and 21.3 mL (95% CI −29.0 to −13.6 mL) after PMVR. ICC between 3D TEE and 2D TEE was 0.363 before PMVR and 0.177 after PMVR.
After PMVR, a residual medial and lateral regurgitation jet could be defined by 2D echocardiography in all patients with a remaining bigger color Doppler jet area located medial (1.5±1.1 cm²) and a smaller jet area located lateral to the clip (1.2±1.1 cm²).

### Clip Position Relative to the Commissural Line
Postprocedural analysis of the clip position using 3D TEE demonstrated a location slightly lateral to the center of the mitral valve commissural line (0.03±0.23 cm lateral), with a range from 0.35 cm medial to 0.67 cm lateral to the central position.

### Effectiveness of PMVR Related to Annular Size
Before PMVR, the mitral valve annulus area determined by 3D TEE was 13.2±5.8 cm², the annulus circumference was 13.5±2.9 cm, the anterior to posterior mitral annulus diameter was 3.7±0.7 cm, and the posteroomedial to anterolateral diameter was 4.1±0.8 cm. Patients with a reduction of 3D TEE regurgitant VCA >50% after the procedure (n=27) had a smaller preprocedural mitral annulus area compared with patients with a reduction ≤50% (n=12) (11.9±3.5 versus 16.1±8.5 cm²; P=0.036). Mitral annulus circumference, mitral annulus anterior to posterior diameter, and annulus posteroomedial to anterolateral diameter tended to be smaller in patients with reduction of 3D TEE regurgitant VCA >50% (Table 3). Mitral annulus area was the only predictor for reduction of regurgitant VCA >50% (odds ratio 0.964 per additional cm² VCA before PMVR; 95%CI 0.913 to 0.991; P=0.0323).

### Six Months Follow-Up Echocardiography
RVs determined by subtracting forward stroke volume from 2D LV stroke volume were unchanged at 6 months after PMVR (15.0±11.9 mL) compared with those immediately after the procedure (15.3±10.4 mL; P=0.8949).

Left atrial and ventricular volumes decreased significantly at 6 months follow-up after PMVR. The reduction in left atrial volume as well as LV end-diastolic volume at 6 months follow-up was significantly greater in patients with a reduction of regurgitant VCA >50% after PMVR as defined by 3D TEE compared with those patients with a reduction of regurgitant VCA ≤50% (Table 4). Two dimensional TTE-based analysis of RVs (subtraction of LV outflow from 2D LV stroke volume) demonstrated only nonsignificant differences between patients with a reduction of RV >50 and ≤50% in subsequent changes of left atrial, LV end-diastolic, and end-systolic volumes at 6 months follow-up (−8.9±6.7% versus −11.3±6.1%; P=0.382, −9.6±9.1% versus −7.0±4.7%; P=0.442 and −6.3±7.5% versus 5.0±7.8%; P=0.669). Similarly, if analysis of RVs based on 2D TEE flow convergence method was applied, there was no significant difference between patients with reduction of RV >50% and ≤50% with regard to subsequent remodeling of left atrial, LV end-diastolic and end-systolic volumes (−9.3±6.9 versus −11.1±4.4%; P=0.666, −9.5±8.5 versus −3.6±4.1%; P=0.240 and −6.3±7.7 versus −2.4±1.2%; P=0.394).

### Change of Mitral Inflow Function
The maximum diastolic MV A area before the procedure determined by planimetry in 3D zoom mode was 6.0±2.0 cm². Diastolic MVA was reduced after the procedure. The remaining

### Table 3. Impact of Mitral Valve Annulus Dimensions on Reduction of the Total Mitral Regurgitation VCA After PMVR Determined by 3D TEE Color Doppler Direct Planimetry

<table>
<thead>
<tr>
<th></th>
<th>Reduction of VCA &gt;50% (n=27)</th>
<th>Reduction of VCA ≤50% (n=12)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mitral valve annulus area, cm²</td>
<td>11.9±3.5</td>
<td>16.1±8.5</td>
<td>0.036</td>
</tr>
<tr>
<td>Mitral annulus circumference, cm</td>
<td>13.0±2.0</td>
<td>14.8±4.1</td>
<td>0.112</td>
</tr>
<tr>
<td>Mitral annulus anterior to posterior diameter, cm</td>
<td>3.5±0.7</td>
<td>3.9±0.8</td>
<td>0.163</td>
</tr>
<tr>
<td>Mitral annulus posteroomedial to anterolateral diameter, cm</td>
<td>4.0±0.7</td>
<td>4.4±1.1</td>
<td>0.263</td>
</tr>
</tbody>
</table>

3D indicates 3-dimensional; PMVR, percutaneous mitral valve repair; TEE, transesophageal echocardiography; and VCA, vena contracta area.

### Table 4. Left Atrial Volume, LVEDV and LVESV at Baseline and Relative Volume Changes at 6 mo After PMVR Defined by 2D TTE Related to Reduction of the Total Mitral Regurgitation VCA After Procedure as Determined by 3D TEE

<table>
<thead>
<tr>
<th></th>
<th>Reduction of VCA &gt;50% (n=25)</th>
<th>Reduction of VCA ≤50% (n=11)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA volume at baseline, mL</td>
<td>160.6±68.0</td>
<td>157.5±52.9</td>
<td>0.896</td>
</tr>
<tr>
<td>LVEDV at baseline, mL</td>
<td>205.2±106.7</td>
<td>205.0±107.1</td>
<td>0.996</td>
</tr>
<tr>
<td>LVESV at baseline, mL</td>
<td>123.6±98.6</td>
<td>120.8±95.1</td>
<td>0.938</td>
</tr>
<tr>
<td>Δ LA volume 6 mo after PMVR, %</td>
<td>−11.4±5.2</td>
<td>−4.8±7.7</td>
<td>0.005</td>
</tr>
<tr>
<td>Δ LVEDV 6 mo after PMVR, %</td>
<td>−11.0±7.2</td>
<td>−4.5±9.3</td>
<td>0.028</td>
</tr>
<tr>
<td>Δ LVESV 6 mo after PMVR, %</td>
<td>−6.5±8.5</td>
<td>−4.9±4.3</td>
<td>0.548</td>
</tr>
</tbody>
</table>

2D indicates 2-dimensional; LA, left atrium; LVEDV, left ventricular end-diastolic volume; LVESV, left ventricular end-systolic volume; PMVR, percutaneous mitral valve repair; TEE, transesophageal echocardiography; and VCA, vena contracta area.
maximal medial valve area was 1.5±0.7 cm² and the maximal lateral valve area was 1.4±0.5 cm², resulting in a total remaining valve area of 2.9±0.9 cm² (reduction by 52.5% after PMVR). Mitral valve mean diastolic pressure gradient increased from 1.6±0.9 mm Hg preintervention to 3.3±1.8 mm Hg postintervention (P<0.001). There was an inverse correlation between MVA before PMVR and postprocedural Pmean (r=−0.63). Using a receiver-operating characteristics analysis, an MVA <4.1 cm² was an excellent predictor for a Pmean ≥5 mm Hg after PMVR (area under the curve 1.0). Patients with a maximal MVA preintervention ≥4.1 cm² (n=33) had a lower postprocedural Pmean compared with patients (n=6) with an MVA <4.1 cm² (2.6±1.1 mm Hg versus 6.7±0.8 mm Hg; P<0.001).

Observer Agreement
The intraobserver variability for the RV determined by subtracting LV outflow from 2D total LV stroke volume was 12.8±12.1% (ICC=0.909) before and 39.3±86.8% after PMVR (ICC=0.941), whereas the interobserver variability for this method was 14.3±12.6% (ICC=0.887) before and 42.2±12.1% (ICC=0.913) after PMVR. Intraobserver variability of RV based on 3D TEE direct planimetry of VCA was 8.4±5.6% (ICC=0.983) before and 16.2±10.0% (ICC=0.959) after PMVR, whereas the interobserver variability for this methods was 10.1±6.1% (ICC=0.978) before and 18.8±11.8% (ICC=0.942) after PMVR.

Discussion
The major findings of this study are as follows: mitral regurgitation volume is reduced by 59% after PMVR as assessed by 3D TEE; PMVR effectiveness as well as postprocedural mitral valve gradient are related to parameters of preprocedural mitral valve morphology defined by 3D echocardiography; greater effectiveness of PMVR is associated with greater reduction of left atrial and LV volumes at 6 months follow-up, whereas the relative reduction in mitral regurgitation volume is similar for the different echocardiographic modalities, the absolute mitral regurgitation volumes defined by 3D and 2D imaging techniques are significantly different.

Analysis of Mitral Regurgitation Severity
Planimetry of regurgitant jet area by 2D color Doppler is known as a semiquantitative method for assessment of mitral regurgitation severity. In a phantom model, planimetry of the regurgitant jet area has been shown to overestimate regurgitation severity. In a phantom model, the hemodynamic behavior of a double-orifice mitral valve did not differ from a physiological 1-orifice valve of same total area and same pressure gradient. In previous studies, total MVA was reduced by 31% to 44% after PMVR. In this study, a postprocedural reduction of MVA by 52.5% has been shown by 3D TEE planimetry. The minor reduction seen in previous studies may be due to the obliquity when measuring the valve areas after PMVR in only 1 plane by 2D echocardiography. This can overestimate each area of postprocedural mitral valve double-orifice resulting in an underestimation of the procedural reduction of MVA.

Mitr-valve Area
Three dimensional echocardiography has been shown to be a precise technique to assess maximum diastolic MVA. In an in vitro model, the hemodynamic behavior of a double-orifice mitral valve did not differ from a physiological 1-orifice valve of same total area and same pressure gradient. In this study, all patients with an MVA <4.1 cm² by 3D TEE preintervention had a mitral valve diastolic mean pressure gradient ≥5 mm Hg after edge-to-edge repair, confirming that the previously arbitrarily applied exclusion criteria for PMVR is correct if postprocedural mitral stenosis should be prevented.

Both, 3D TEE data sets with or without color Doppler have been used for direct visualization of mitral regurgitant orifice areas. Direct planimetry of VCA by 3D color Doppler echocardiography has been shown to allow precise quantification of mitral valve regurgitation validated against magnetic resonance imaging. Similarly, analysis of mitral regurgitant areas and volumes based on 3D TEE without color has recently been validated against magnetic resonance imaging. In patients with mitral regurgitation, regurgitant orifice area was found to be the most robust parameter for quantification of lesion severity. A transfer of the excellent results obtained in 1-orifice mitral valve morphology to the 2-orifice morphology after PMVR seems adequate, as this modality for quantification of regurgitant severity is based on direct visualization of mitral regurgitant orifice areas. In this study, mitral regurgitation volumes were found to be substantially greater using quantification based on direct planimetry of VCA by 3D color Doppler TEE when compared with a definition of regurgitation volumes by subtracting LV outflow from 2D TTE stroke volume. This difference was seen before as well as after the procedure. The difference should be explained by the known underestimation of volumes by the 2D method. However, reduction of mitral regurgitation fraction was of the same magnitude irrespective of applied method for quantification. Three dimensional TEE has a unique advantage in that it allows analysis of mitral regurgitation severity for each orifice of the double-orifice mitral valve after PMVR. Assessment of EROA before and sum of the medial and the lateral EROA after edge-to-edge repair by 2D color Doppler TEE seems to overestimate the procedural reduction of mitral regurgitation compared with subtracting LV outflow from total stroke volume or direct planimetry of VCA by 3D TEE. The smaller intra- and interobserver variability of RV measures by 3D echocardiography allows better detection of RV changes during serial studies compared with 2D echocardiography.

Effects of Percutaneous Mitral Valve Repair
Impact of Mitral Annulus Dimensions on Effective Reduction of Mitral Regurgitation

In this study, PMVR was associated with less procedural success in patients with enlarged preprocedural mitral annulus. This finding relates to previous reports on the surgical edge-to-edge repair, which has been shown to be unsuccessful in patients with significant annulus dilation and enlarged septal to lateral annulus distance. However, only mitral annulus area defined by 3D TEE was found to be a predictor of a reduction in mitral regurgitant VCA >50%, although diameters were not significant. This finding supports the importance of 3D imaging for preprocedural patient selection and prediction of procedural effectiveness.

Impact of Procedural Effectiveness on Left Atrial and Ventricular Volumes

PMVR has been demonstrated to be similarly effective in reducing LV volumes at follow-up compared with surgical repair. This study extended this observation of reduced volumes at follow-up to the left atrium. In addition, changes in left atrial and LV volumes were significantly greater in patients with a reduction of regurgitant VCA >50% than in those with a reduction ≤50% after the procedure.

Limitations

Patients were evaluated within 24 hours before, within 24 hours after PMVR, and at 6 months follow-up. No information on long-term results was obtained. Only echocardiographic methods have been used for quantification of mitral regurgitation severity, and no independent imaging method was applied. The applied 2D echocardiography-based methods to evaluate mitral regurgitation are not validated for post-procedural double-orifice mitral valve morphology. However, there is no validated method for quantification of mitral regurgitation after the PMVR procedure, which can be applied in the majority of patients. Cardiac magnetic resonance tomography has been shown to be feasible in patients after PMVR, but pre-existing cardiac device therapy prevents the use of magnetic resonance imaging for precise assessment of mitral regurgitation in a high rate of patients undergoing PMVR.

Clinical Implications

This study showed that mitral valve RVs before and after PMVR can be evaluated with lower intra- and interobserver variability using 3D TEE compared with 2D echocardiography based methods. This may allow better assessment of procedural effects during serial analysis of mitral regurgitant severity pre- to postprocedure. Three dimensional TEE used for preprocedural analysis of mitral valve morphology allows definition of patients with greater procedural effectiveness and greater risk of postprocedural mitral valve stenosis. Furthermore, the 3D TEE based analysis of procedural effectiveness allows an improved definition of patients with subsequent remodeling of left atrial and LV remodeling.

Conclusions

Three dimensional echocardiography demonstrates significant reduction of RV after PMVR. The unique visualization of the mitral valve by 3D TEE allows improved understanding of the morphological and functional changes induced by PMVR as well as prediction of procedural effectiveness.

Disclosures

None.

References

Percutaneous mitral valve repair has been demonstrated to be effective for reduction of mitral regurgitation. However, com-

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vitamir commissurotomy in patients with mitral stenosis.

R. Comparison of accuracy of mitral valve regurgitation volume deter-


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Effects of Percutaneous Mitral Valve Repair

CLINICAL PERSPECTIVE

Percutaneous mitral valve repair has been demonstrated to be effective for reduction of mitral regurgitation. However, com-

commonly used 2 dimensional (2D) echocardiography based techniques are not validated for postprocedure double-orifice mitral

and may be limited in the accurate quantification of procedural effects on mitral morphology and function. This study

showed that mitral valve regurgitant volumes pre- and postpercutaneous mitral valve repair can be evaluated with lower intra-

and interobserver variability using 3D transesophageal echocardiography (TEE) compared with 2D echocardiography-

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3D TEE-based analysis of procedural effectiveness allows an improved definition of patients with subsequent left atrial and

left ventricular remodeling. In clinical practice, preprocedural 3D TEE based analysis of the mitral valve geometry may be

used to predict the effectiveness of percutaneous mitral valve repair and postprocedural application of 3D TEE allows an

improved understanding of the morphological and functional changes induced by the intervention.
Analysis of Procedural Effects of Percutaneous Edge-to-Edge Mitral Valve Repair by 2D and 3D Echocardiography

Ertunc Altiok, Sandra Hamada, Kathrin Brehmer, Kathrin Kuhr, Sebastian Reith, Michael Becker, Jörg Schröder, Mohammad Almalla, Walter Lehmann, Nikoalas Marx and Rainer Hoffmann

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