Cardiac magnetic resonance imaging (MRI) is a new method that allows one to evaluate cardiac structures and function noninvasively (1). Recently, the feasibility of velocity-encoded MRI, which closely correlates with echocardiography (ECHO), has been demonstrated for the assessment of stenotic aortic (2) and mitral valves (3). However, with new balanced gradient-echo sequences, direct visualization of valve area is also possible, and in patients with aortic stenosis, it has been shown that the valve area, as assessed by MRI planimetry, closely corresponds to the invasively assessed valve area, as assessed by cardiac catheterization (CATH) (4,5). Thus, planimetry of the mitral valve area (MVA) by MRI might as well offer an alternative noninvasive method in the diagnosis of mitral stenosis (MS).

The aim of this study was to evaluate the accuracy and clinical utility of planimetry of the MVA by MRI in comparison with the echocardiographically calculated valve area (ECHO-MVA) and invasively derived MVA at catheterization (CATH-MVA). We hypothesized that planimetry of MVA by MRI is feasible and safe and offers an alternative noninvasive method for noninvasive quantification of mitral stenosis. In the clinical management of patients with mitral stenosis, it has to be considered that planimetry by MRI slightly overestimates MVA, as compared with MVA calculated echocardiographically and at catheterization. (J Am Coll Cardiol 2005;45:2048–53) © 2005 by the American College of Cardiology Foundation
an investigator experienced in the technique, without knowledge of previous velocity or pressure gradient measurements.

**MRI studies.** For left ventricular functional analysis, cine images were acquired on a 1.5-T scanner (Sonata, Siemens Medical Solutions, Erlangen, Germany) using a phased-array receiver coil and breath-hold acquisitions (13 heartbeats) prospectively gated to the electrocardiogram with a balanced GRE sequence (true FISP; slice thickness 8 mm, echo time 1.53 ms, pixel bandwidth 1,085 Hz, repetition time 3.14 ms leading to a temporal resolution of 43 ms, matrix 256 × 202). The number of Fourier lines per heartbeat was adjusted to allow the acquisition of 18 to 20 cardiac phases within a cardiac cycle. The field of view was 340 mm on average and adapted to the size of the patient.

For the evaluation of the mitral valve, a retrospectively gated balanced GRE sequence (true FISP) approach was selected in order to cover the full cardiac cycle. The sequence was executed with a repetition time of 3.13 ms, and phase encoding was advanced every 1,200 ms. Data were normalized and resorted in time throughout the cardiac cycle, leading to a temporal resolution of 47 ms. The number of views per cardiac cycle was selected to be between 17 and 30, depending on the patient’s heart rate. Data were collected during a breath-hold (14 heart beats, slice thickness 5 mm, echo time 1.57 ms, pixel bandwidth 930 Hz, matrix 256 × 205, excitation angle 59°). The field of view was 340 mm times 276 mm on average and adapted to the size of the patient.

The imaging plane of the mitral valve was defined by acquiring diastolic four-chamber, three-chamber, and long-axis two-chamber views. The subsequent slices were defined perpendicular to the valvular plane and, in cases of orifices with an eccentric outlet, perpendicular to the origin of the jet in the left ventricle (Fig. 1). Depending on the morphology of the mitral valve, four to six slices parallel to the mitral valve orifice (short-axis view) were assessed. Starting at the base of the valve and moving toward the tip of the cusps, the visible orifice area continuously decreased. The most apical slice that was still located at the maximum diastolic opening on the tip of the cusps was chosen for planimetry of MVA. We selected the time point within the cardiac cycle at which maximum diastolic mitral valve opening was observed in the three-chamber view. At precisely the same time point, MVA was planimetered in the short-axis view. We placed our traces at the point of the bright pixels. Areas of signal void in severely calcified valves or in areas of very turbulent flow were counted as part of the valve leaflet.

Planimetry was performed by two independent observers who were unaware of each other’s interpretations and the ECHO and CATH results. At least three measurements were performed by each observer. For calculating MVA, the mean value of the two observers was used. Image quality was semiquantitatively scored by each observer in three grades (good, moderate but still evaluable, and not sufficient for evaluation).

**Statistical analysis.** Results are expressed as the mean value ± SD. The agreement among the three methods of quantification of the MVA was assessed by univariate regression analysis and by the Bland–Altman method. Differences in mean values between two groups were analyzed by the Student t test. The chi-square test was performed to compare frequencies between groups. The ROC analysis was carried out to determine predictive values of MRI to detect MS (MVA ≤1.5 cm²), as defined by catheterization.

### Table 1. Patient Characteristics

<table>
<thead>
<tr>
<th></th>
<th>MRI-MVA &gt;1.5 cm²</th>
<th>MRI-MVA ≤1.5 cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yrs)</td>
<td>61 ± 4</td>
<td>62 ± 4</td>
</tr>
<tr>
<td>Gender (% female)</td>
<td>86</td>
<td>50</td>
</tr>
<tr>
<td>CAD (%)</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>NYHA functional class (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>64</td>
<td>37</td>
</tr>
<tr>
<td>III</td>
<td>21</td>
<td>63*</td>
</tr>
<tr>
<td>Prior valvuloplasty (%)</td>
<td>43</td>
<td>13</td>
</tr>
<tr>
<td>Sinus rhythm (%)</td>
<td>50</td>
<td>62</td>
</tr>
<tr>
<td>Mitral regurgitation (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0–I</td>
<td>64</td>
<td>100</td>
</tr>
<tr>
<td>II–III</td>
<td>36</td>
<td>0</td>
</tr>
<tr>
<td>MRI-CO (l/min)</td>
<td>4.1 ± 0.3</td>
<td>3.6 ± 0.4</td>
</tr>
<tr>
<td>MRI-EF (%)</td>
<td>59 ± 2</td>
<td>59 ± 4</td>
</tr>
</tbody>
</table>

*p = 0.05. Mean ± SEM.

CAD = coronary artery disease; CO = cardiac output; EF = ejection fraction; MRI = magnetic resonance imaging; MVA = mitral valve area; NYHA = New York Heart Association.
A level of significance of \(<0.05\) was defined as statistically significant.

**RESULTS**

**Patient characteristics.** Most patients were symptomatic with exertional dyspnea, and New York Heart Association functional class III was more prevalent in patients with more severe MS (\(p<0.05\)). Patients with less severe MS have had previous valvuloplasty more frequently (\(p=NS\)) and more concomitant mitral regurgitation (\(p=NS\)). Cardiac output (derived from cardiac MRI) was higher in patients with less severe MS (\(p=NS\)). Patient characteristics are depicted in Table 1.

**MVA.** The mean MRI-MVA determined by planimetry was \(1.61 \pm 0.42 \text{ cm}^2\) (range 0.6 to 2.50 cm\(^2\)). Hemodynamic results (i.e., cardiac output and ejection fraction) are shown in Table 1. Image quality in patients with sinus rhythm (\(n=12\)) was of overall good quality. Image quality in patients with atrial fibrillation was of good quality in 6 of 10 patients. Interobserver and intraobserver variabilities (coefficient of variation) were \(0.03 \pm 0.01 \text{ cm}^2\) and \(0.04 \pm 0.02 \text{ cm}^2\), respectively.

As assessed by ECHO, the mean ECHO-MVA was \(1.48 \pm 0.42 \text{ cm}^2\) (range 0.70 to 2.50 cm\(^2\)), and as assessed by cardiac catheterization, the mean CATH-MVA calculated by the Gorlin-formula was \(1.52 \pm 0.49 \text{ cm}^2\) (range 0.60 to 2.4 cm\(^2\)).

**Comparison of MRI with CATH.** The correlation between MRI- and CATH-MVA was very good (\(n=17, r=0.89, p<0.0001\)). The mean absolute difference between MVA derived by MRI and the Gorlin formula was \(0.08 \pm 0.22 \text{ cm}^2\) (\(p=NS\)), resulting in a slight but not significant overestimation of the MRI-MVA compared with CATH-MVA by 5.0%. As shown in the Bland-Altman analysis, there were no outliers beyond 2 SD of the mean difference of both methods (Fig. 2).

**Comparison of MRI with ECHO.** The correlation between planimetry of the MRI- and ECHO-MVA was very good (\(r=0.81, p<0.0001\)). The mean absolute difference between MVA derived by MRI and ECHO was \(0.13 \pm 0.24 \text{ cm}^2\) (\(p<0.05\), resulting in a slight overestimation of the MRI-MVA as compared with ECHO-MVA by 8.1% (Fig. 3).

**Comparison of ECHO to CATH.** The correlation between ECHO-MVA and CATH-MVA was close (\(n=17, r=0.69, p<0.002\)). The mean absolute difference between MVA derived by ECHO and CATH was \(0.04 \pm 0.29 \text{ cm}^2\) (\(p=NS\)) (Fig. 4).

**Predictive values of MRI in detecting stenosis.** As assessed by ROC analysis, MRI detected MS (defined as...
MVA $\leq 1.5 \text{ cm}^2$ at catheterization) at a MRI-MVA threshold of $<1.65 \text{ cm}^2$ with high accuracy (sensitivity 89% and specificity 75%, ROC area 0.9). The positive and negative predictive values were 80% and 86%, respectively (Table 2).

**DISCUSSION**

The current study demonstrates that visualization and planimetry of MVA by MRI is possible and reliable in patients with MS. We found a very good correlation of MVA planimetry with the invasively derived data by the Gorlin formula and the noninvasively derived data by the Doppler pressure half-time method. Furthermore, MRI obtained excellent predictive values for the detection of MS.

In patients with MS, the symptoms of dyspnea and fatigue are often difficult to quantify and do not always reflect genuine reductions in mitral orifice area (8). Because of the continuous and progressive nature of MS, repeated assessment of the valve area is often necessary, and the ability to accurately assess the valve area noninvasively is of great importance. In this respect, the excellent predictive values suggest that MRI as a noninvasive method might prove highly useful for the stratification of patients with

**Figure 2.** (A) Scattergram of mitral valve area (MVA) determined by magnetic resonance imaging (MRI) and cardiac catheterization (CATH) in 17 patients. (B) Bland-Altman plot of the average mean versus the differences between MRI planimetry and MVA derived at CATH. The solid line is the mean difference; the dotted lines mark the standard deviations of the differences.

**Figure 3.** (A) Scattergram of MVA determined by MRI and echocardiography (ECHO) in 22 patients. (B) Bland-Altman plot of the average mean versus the differences between MRI planimetry and MVA derived at ECHO. The solid line is the mean difference; the dotted lines mark the standard deviations of the differences. Abbreviations as in Figure 2.
suspected MS. In addition to the assessment of valve area, MRI is also able to detect leaflet or chordal apparatus thickening and left atrial or atrial appendage thrombi and allows one to assess the presence and severity of concomitant regurgitation. Consideration of the valve area, as well as these important aspects, is of pivotal importance for therapeutic decision-making and either conservative, percutaneous, or surgical management of patients with MS.

In the current study, we report a slightly higher mean MVA by MRI with the methods used in this study, in comparison to CATH (5%) and ECHO (8%). In addition, ROC analysis determined that detection of CATH-MVA < 1.5 cm² was best achieved at a MRI-MVA threshold of < 1.65 cm². Both findings therefore demonstrate a slight but systematic overestimation of MVA by MRI. The underlying mechanism is currently unclear and may be related to MRI technology or the direct visualization of valve opening, as compared with indirect estimation by CATH or ECHO. Another explanation for the overestimation of valve orifice might be volume averaging from the cine MRI slice thickness chosen. Transplanar valve motion during diastole might also lead to overestimation of the valve area, particularly when the imaging plane misses the smallest orifice area. Nevertheless, we addressed this problem by acquiring at least four slices at different levels of the mitral valve and recommend this approach to minimize the potential of mitral valve area overestimation because of imprecise localization. Nevertheless, the obtained cut-off values, which have been calculated retrospectively, will now have to be assessed in a prospective study.

In routine clinical practice, both CATH and ECHO are used to assess MS. Cardiac catheterization is widely accepted as the gold standard, and MVA is calculated by the Gorlin formula from the mean transvalvular gradient and valvular flow (6). Because of the indirect measurements, however, the accuracy of MVA calculation has often been challenged (9,10). Despite these limitations, the Gorlin formula remains the standard criterion against which new noninvasive methods must be judged.

Visualization and planimetry of MVA by ECHO provide a noninvasive measurement and are widely used for estimation of MVA (11–13). Although the Doppler pressure half-time method used in this study has proven valuable in the noninvasive assessment of the severity of MS in a variety of circumstances, its accuracy may also be limited in a variety of conditions (7,14).

Together, this variability in MVA measurements by different methods underscores the importance of understanding the assumptions and limitations of each method and supports a noninvasive method for direct determination of MVA by planimetry such as MRI. The current study is the first to utilize cine MRI for direct visualization and planimetry of MVA, and our results indicate that MRI planimetry is accurate. This new method therefore comple-

Table 2. MRI Planimetry of MS, Predictive Values for Given CATH-MVA

<table>
<thead>
<tr>
<th>CATH-MVA (cm²)</th>
<th>Cases/Total (n)</th>
<th>MRI-Cutoff (cm²)</th>
<th>ROC Area (95% CI)</th>
<th>Sens./Spec. (%)</th>
<th>PPV/NPV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MVA ≤ 1.5 cm²</td>
<td>10/17</td>
<td>≤ 1.65</td>
<td>0.90 (0.76–1.0)</td>
<td>89/75</td>
<td>80/86</td>
</tr>
</tbody>
</table>

CATH = cardiac catheterization; CI = confidence interval; MRI-Cutoff = optimal cutoff for MRI-MVA to detect the given CATH-MVA; MS = mitral stenosis; MVA = mitral valve area; NPV = negative predictive value; PPV = positive predictive value; ROC = receiver-operator characteristic; Sens. = sensitivity; Spec. = specificity.
ments established MRI methods of valve assessment, such as velocity mapping (2,3).

Conclusions. Magnetic resonance imaging allows for noninvasive planimetry of MVA with good image quality and also provides additional information on valve structure and function. In the clinical management of patients with MS, it has to be considered that, despite a close correlation, MRI with the methods used in this study slightly overestimates MVA, as compared with CATH and ECHO.

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REFERENCES