Long-Term Outcomes of Significant Mitral Regurgitation After Percutaneous Mitral Valvuloplasty

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Background—Mild commissural mitral regurgitation (MR) is associated with significantly higher restenosis-free survival after percutaneous mitral valvuloplasty (PMV), which suggests that different mechanisms of significant MR after PMV may have different clinical courses. We therefore analyzed long-term prognostic factors of significant MR after PMV.

Methods and Results—Echocardiographic and clinical follow-up data on 380 patients were analyzed (286 women, mean age 44±11 years) who underwent PMV with the Inoue balloon technique between 1995 and 2000. Significant MR developed in 47 patients (12.4%). The survival rate at 8 years was 96±3% and 98±10% in patients with and without significant MR, respectively (P=0.084). The most frequent mechanism was commissural MR, or MR that originated at the site of successful commissurotomy, which occurred in 27 of 47 patients (57%), whereas noncommissural MR occurred in 20 (43%) patients, 12 (26%) with subvalvular damage resulting in chordae rupture and flail motion and 8 (17%) with leaflet laceration. The 8-year event-free survival rate was significantly lower in patients with significant MR than in those without (47±8% versus 83±3%, P<0.001) and was significantly higher in patients with commissural versus noncommissural MR (63±11% versus 29±11%, P<0.001). Of the 47 patients with significant MR, who were followed up for 74±29 months, 19 patients (40%) underwent mitral valve replacement, and 28 patients (60%) received medical treatment only. Patients with commissural MR had a significantly lower rate of mitral valve replacement than patients with noncommissural MR (15% versus 70%, P<0.001). Multivariate analysis showed that atrial fibrillation (odds ratio, 7.4; 95% CI, 1.1 to 56.4; P=0.038), mean mitral gradient immediately after PMV (odds ratio, 1.5; 95% CI, 1.1 to 2.0; P=0.009), and the mechanism of MR (odds ratio, 16.7; 95% CI, 2.3 to 122.2; P=0.005) were independent factors associated with mitral valve replacement.

Conclusions—Clinical outcome of patients with significant MR after PMV varied according to MR mechanism and the adequacy of hemodynamic improvement, which is easily assessed by echocardiography immediately after PMV. (Circulation. 2006;114:2815-2822.)

Key Words: echocardiography • valvuloplasty • regurgitation • mitral valve stenosis

Percutaneous mitral valvuloplasty (PMV) is an effective treatment option for hemodynamically significant mitral stenosis and has become the procedure of choice in patients with suitable valve anatomy.1–6 The increased clinical application and cumulative clinical experience of this invasive procedure have been accompanied by significant improvements in its success rate and safety. Severe mitral regurgitation (MR), however, has emerged as the most frequent and serious complication of PMV, and its frequency has been reported to be stable over time.7 Although increases in mitral valve area after PMV are largely the result of separation of the mitral leaflets along the natural planes of their commissures,8–11 many additional mechanisms have been reported to contribute to the development of significant MR after PMV, including excessive commissural split and disruption of chordal or valvular anatomy.12 In addition, clinical tolerance to immediately produced significant MR is variable, and although some patients require emergency surgery, others do not need it, and a few may even have a decrease in the severity of MR over time.13–18 All these observations raise the necessity of systematic investigation of long-term outcomes in larger numbers of patients. Furthermore, it is important to determine whether splitting of fused commissures, the mechanism by which the mitral valve area increases after PMV, is also responsible for the observed exacerbation in MR after PMV. In a previous report, we found that mild commissural MR, defined as MR that originated from the medial or lateral commissure on color flow imaging, was frequently observed...

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Circulation is available at http://www.circulationaha.org DOI: 10.1161/CIRCULATIONAHA.106.658088

Received August 14, 2006; revision received September 28, 2006; accepted October 19, 2006.
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in patients with successful immediate results and was an independent factor associated with significantly higher restenosis-free survival rate after PMV. We therefore hypothesized that different mechanisms of significant MR after PMV may have different impacts on clinical course; specifically, that patients with commissural MR of moderate and significant degree have more favorable clinical courses. To test this hypothesis, we have analyzed long-term clinical and echocardiographic follow-up data in our patient cohort.

Methods

Study Population

From January 1995 to December 2000, a total of 411 consecutive patients with suitable morphology and condition underwent PMV with the Inoue balloon technique. We excluded 2 patients who underwent emergency operations because of leaflet laceration and chordae rupture and 29 patients who had unsuccessful immediate results, with mitral valve area <1.5 cm² on follow-up echocardiography. The study population thus comprised 380 patients (286 women, mean age 44±11 years) with mitral valve area 0.9±0.2 cm² and total echocardiographic score 7.4±1.3.

Percutaneous Mitral Valvuloplasty

After cardiac catheterization confirmed severe mitral stenosis without significant MR, experienced physicians performed PMV with the Inoue balloon technique while monitoring the conventional hemodynamic parameters. The balloon size was chosen to obtain an effective balloon dilation area/body surface area of approximately 4 cm²/m², and 1-step dilation was performed.5

Echocardiographic Evaluation

Comprehensive 2-dimensional and color Doppler echocardiographic evaluation was performed in all patients on the day before and 24 hour after PMV with a Sonos 2500 or 5500 imaging system equipped with a 2.5-MHz transducer (Hewlett Packard, Palo Alto, Calif). The morphological features of the mitral valve were categorized as described previously,19 and the total echocardiographic score was obtained by adding the scores of each of these individual morphological features: leaflet mobility, thickness, calcification, and subvalvular lesions. The mitral valve area was measured by direct planimetry at the parasternal short axis view, and the continuous wave Doppler technique was used to calculate the mitral gradient and the peak pressure gradient of tricuspid regurgitation.

Within 24 hours of PMV, the mitral valve area was measured, and the mitral gradient and peak pressure gradient of tricuspid regurgitation were calculated. In addition, the extent of the commissurotomy or separation of the commissures, primarily at the parasternal short axis and the apical 2-chamber view, and the development of MR were assessed. The echocardiographic criterion of successful commissurotomy was the development of new echocardiographic dropout in the region of one or both commissures at the maximal opening.5,12 Color Doppler flow imaging was performed with multiple orthogonal parasternal and apical views for diagnosis and quantification of MR after PMV.20 Semiquantification of MR was done with the MR jet area; a MR jet-to-left atrial area ratio of 5% to 25% was graded as +1, 26% to 50% as +2, 51% to 75% as +3, and 76% to 100% as +4.13 The definition of significant MR was based on color Doppler flow imaging findings, which included a MR jet-to-left atrial area ratio >50%, an MR jet area >10 cm², or a radius of the proximal isovelocity surface area ≥0.7 cm at the aliasing velocity of 40 cm/sec.

Diagnosis of commissural MR was based on a clearly definable jet of MR that originated at the site of successful commissurotomy (Figure 1). Other mechanisms of MR included disruption of the valvular or subvalvular apparatus, which resulted in leaflet laceration (Figure 2) or flail (Figure 3). In patients with significant MR, transesophageal echocardiography was performed to determine its mechanism. The mechanism of MR was determined by 2 independent observers (M.-J.K. and J.-K.S), who disagreed with regard to 4 patients (8%); the final decision was reached by the third observer (D.-H.K) in these cases.

Data Analysis

Patients with significant MR were divided into 2 groups, those with commissural MR (group 1) and those with noncommissural MR as a result of leaflet laceration or flail (group 2). Clinical follow-up was performed 2 and 6 months after PMV and every year until December 2004. Clinical data were collected either during patient visits to the outpatient clinic or by telephone interviews. Clinical events included cardiac death, mitral valve replacement (MVR), second PMV, embolism, and hospital admission as a result of congestive heart failure. Echocardiographic follow-up data were obtained at 1-year intervals until December 2004. Clinical and echocardiographic follow-up was completed in 369 patients (97%), with mean follow-up periods of 68±30 months (range: 3 to 125) and 57±33 months (range: 2 to 122), respectively. The primary analysis of clinical outcomes was based on the intention-to-treat principle.

All data were expressed as mean±SD. Measurements before and after PMV were compared with the Student paired t test, and comparisons between groups with the unpaired Student t test for continuous variables. The χ² or Fisher exact test was used for frequency ratios between groups. Kaplan-Meier analysis was used to determine clinical event–free survival rate, and between-group differences in survival rates were assessed with the log-rank test. Clinical and echocardiographic variables were compared between patients who underwent MVR and those who received medical treatment only after development of significant MR; variables with P<0.1 were used for multivariate analysis to determine factors associated with MVR for traumatic significant MR after PMV. All statistical analyses were performed with SPSS version 12.0 for Windows (SPSS, Chicago, IL). P<0.05 indicated statistical significance in all analyses.

The authors had full access to the data and take full responsibility for the integrity of the data. All authors have read and agree to the manuscript as written.

Results

Baseline Characteristics and Immediate Outcomes

Of the 380 patients who underwent PMV, immediate follow-up echocardiography showed development of significant MR in 47 patients (12.4%). Comparison of baseline clinical and echocardiographic characteristics of the subjects is summarized in Table 1. Patients who did and did not develop significant MR were similar, with the exception of the larger left atrium in patients who developed significant MR. Immediately after PMV, the mitral valve area did not differ significantly between patients with and without significant MR (1.8±0.3 versus 1.9±0.3 cm², respectively, P=0.69), but mean mitral gradient was significantly higher in patients with significant MR (7.6±3.8 versus 5.2±2.1 mm Hg, P<0.001).

The most frequent mechanism of MR was commissural MR, which occurred in 27 patients (57%), with medial commissural MR (n=16) occurring 2 times more frequently than lateral commissural MR (n=8); the remaining 3 patients showed significant MR that originated from both commissures. Significant subvalvular damage that resulted in chordae rupture and flail motion of the mitral leaflet was observed in 12 patients (26%), and leaflet laceration was seen in only 8 patients (17%). Leaflet laceration developed more frequently in the anterior leaflet (n=6), whereas flail motion developed more frequently in the posterior leaflet (n=7); flail motion of both leaflets developed in 1 patient. Patients with significant
MR were divided into 2 groups according to MR mechanism: those with commissural MR (group 1) and those with noncommissural MR due to leaflet laceration or flail (group 2). There were no significant between-group differences in age, gender, cardiac rhythm, mitral valve area, mitral gradient, systolic pulmonary artery pressure, and Wilkins echocardiographic score. Immediately after PMV, the mitral valve area did not differ significantly between groups (1.8±0.3

**Figure 1.** An illustrative case of development of commissural MR after PMV. A, Two-dimensional echocardiography at the parasternal short axis view showed new echocardiographic dropout at the medial commissure. Clearly definable jet of MR originating at the medial commissure was shown by color Doppler flow mapping at the parasternal short (B), apical 4-chamber (C) and 2-chamber views (D). LA indicates left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

**Figure 2.** An illustrative case of development of significant MR as a result of isolated leaflet laceration or tear after PMV. Parasternal long-axis (A) and apical (D) views show an eccentric MR jet. A parasternal short axis view shows a new echocardiographic dropout (C) at the mid portion of the posterior mitral leaflet with proximal flow convergence (B), which suggests a leaflet tear (arrow). LA indicates left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.
versus 1.9±0.3 cm², respectively, P=0.279), but mean mitral gradient was significantly lower in group 1 than in group 2 (6.3±3.2 versus 8.8±2.8 mm Hg, P=0.002).

**Follow-Up**

Mean clinical and echocardiographic follow-up periods in patients with significant MR were 74±29 months (range: 24 to 133) and 77±34 months (range: 16 to 127), respectively. Development of clinical events during follow-up is summarized in Figure 4. Cardiac death due to heart failure was documented in 3 patients (1%) without significant MR and in 1 patient (2%) with significant MR. The survival rate at 8 years was 96±3% in patients with significant MR and 98±10% in those without significant MR (P=0.084). Eighteen patients with significant MR (41%) underwent MVR due to deterioration of functional class, whereas 4 patients (8%) developed cerebral embolisms. Of the patients without significant MR, 19 (6%) underwent MVR to control heart failure symptoms as a result of restenosis of the mitral valve area. The rate of MVR was significantly lower in patients without significant MR than in those with significant MR (P<0.05). Embolic episodes developed in 4 patients with significant commissural MR. There was no significant difference of embolic event rate between groups (4 of 27 versus 0 of 20, P=0.098), and all 4 patients showed unacceptably low prothrombin time of international normalized ratio <1.5 despite oral anticoagulation at the time of embolism.

The probability of clinical event–free survival in patients with significant MR was 81±6% at 1 year, 66±7% at 3 years, 45±12 43±11

**TABLE 1. Baseline Clinical and Echocardiographic Characteristics in Patients Who Did and Did Not Develop Significant MR After PMV**

<table>
<thead>
<tr>
<th>Significant Mitral Regurgitation (+)</th>
<th>Significant Mitral Regurgitation (−)</th>
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<td>Atrial fibrillation, n (%)</td>
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<td>Peak pressure gradient of TR, mm Hg</td>
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AP indicates anterior-posterior; TR, tricuspid regurgitation. Continuous variables are expressed as mean±SD.

*P=0.018.
61±7% at 5 years, and 47±8% at 8 years. In comparison, the probability of event-free survival in patients without significant MR was 99±1% at 1 year, 94±1% at 3 years, 91±2% at 5 years, and 83±3% at 8 years (Figure 5); patients with significant MR after PMV showed significantly lower event-free survival rates during follow-up (P<0.001). Patients with significant MR showed small (but significantly greater) annual decreases in post-PMV mitral valve area than those without significant MR (Figure 6). Follow-up left atrial size was larger (55±10 versus 50±9 mm, P<0.001) and peak pressure gradients of tricuspid regurgitation were higher (32±10 versus 28±9 mm Hg, P=0.002) in patients with significant MR.

Figure 7 compares the development of clinical events according to the MR mechanism. Patients with commissural MR had a significantly lower rate of MVR than patients with noncommissural MR (15% versus 70%, P<0.001). The probability of clinical event–free survival in patients with commissural MR was 96±4% at 1 year, 89±6% at 3 years, 81±8% at 5 years, and 63±11% at 8 years. In patients with noncommissural MR, the rates were 64±10% at 1 year, 36±10% at 3 years, 36±10% at 5 years, and 29±11% at 8 years (P<0.001). Figure 8 shows the changes in MR severity in the 47 patients with significant MR after PMV. Immediately after PMV, commissural MR that resulted in MR grade +3 was observed in 22 of 27 patients (81%), whereas 15 of 20 patients (75%) with noncommissural MR had MR grade +4. Seventeen patients showed some decrease of MR severity during follow-up, and 4 patients, 3 with commissural MR, showed progression from MR grade +3 to +4. Patients with commissural MR showed a higher prevalence of MR decrease than those with noncommissural MR during follow-up (56% [15 of 27] versus 10% [2 of 20], P<0.001).

During follow-up, MVR was performed in 19 patients (40%), whereas the remaining 28 patients received medical treatment only. Table 2 compares the clinical and echocardiographic variables according to treatment after the development of significant MR after PMV. Patients who underwent MVR showed significantly elevated mean mitral gradient and pulmonary artery pressure immediately after PMV, which persisted during follow-up despite the similar mitral valve area before and after PMV. The prevalence of commissural MR was significantly lower and that of leaflet laceration or flail was higher in patients who underwent surgery during follow-up than in those who received medical treatment only. Multivariate analysis showed that atrial fibrillation (odds ratio, 7.4; 95% CI, 1.1 to 56.4; P=0.038), mean mitral gradient immediately after PMV (odds ratio, 1.5; 95% CI, 1.1 to 2.0; P=0.009), and mechanism of MR (odds ratio, 16.7; 95% CI, 2.3 to 122.2; P=0.005) were independent factors associated with MVR for significant MR after PMV.
Mitral gradient, mm Hg frequently requires intensive medical therapy and surgery, of mitral valve obstruction. Severe MR, however, which from the hemodynamic improvement provided by the relief cases the regurgitation is mild and only minimally detracts MR occurs in up to 15% of patients after PMV and continues to be one of the most important complications of this procedure. In a report that showed temporal trends in PMV from 1986 to 2001, Iung et al found the technical failure rate found to have decreased significantly, whereas the frequency of severe MR remained stable over time.

Initial attempts to determine the relationship between baseline mitral valve morphology or procedural factors and the development of significant MR were unsuccessful. A thorough examination of surgically excised mitral valves revealed that 3 characteristic anatomic features were associated with the development of significant MR after PMV: uneven mitral leaflet thickening, severe and extensive subvalvular deformation, and commissural calcification. Therefore, the original Wilkins mitral valve echocardiographic score was modified, with special emphasis on the uneven distribution of leaflet thickness, degree of commissural disease, and subvalvular disease involvement; with this modification, an MR echocardiographic score ≥10 could predict the development of severe MR with high sensitivity and specificity. Although this score can be useful in patient selection and in the choice of procedural factors, such as balloon size, the new MR echocardiographic score was designed to predict the development of typical leaflet laceration or rupture after PMV on the basis of findings that use surgically excised mitral valves. The finding of leaflet lacerations in surgical specimens of patients who underwent MVR may not be the only mechanism of MR after PMV. There is a marked heterogeneity in the clinical features of patients with significant MR after PMV. Moreover, clinical tolerance to immediately produced severe MR is variable, with some patients requiring emergency surgery and others not needing it, and some patients experiencing a decrease in MR severity over time. All these findings suggest that significant MR is a heterogeneous disease entity in terms of mechanisms and its clinical impact on the natural course after PMV.

There are several different mechanisms of MR after PMV. Echocardiographic analysis showed that noncommissural tearing of the mitral leaflet was the only mechanism in 7 of 40 patients (18%) with significant MR after PMV. A split in fused commissures was found to be responsible for the observed exacerbation in MR after successful PMV, but commissural MR was thought to be mild, of no clinical importance, and the most frequent mechanism by which a mild increase in MR occurs. In a report that involved 280 patients, the incidence of significant MR was ≤10 and was reported to result from 3 echocardiographic mechanisms: subvalvular damage that resulted in chordae rupture (9 of 21 patients), leaflet tearing (6 of 21 patients), and “no recognizable structural abnormalities” and “excessive” widening of the commissures (5 of 21 patients). Differences in patient populations, selection criteria for significant MR, and PMV method (double-balloon versus Inoue balloon technique) may explain the variability in reported echocardiographic mechanisms of MR.

Commissural MR was originally thought to be responsible for the development of mild MR and to be of no clinical significance. We found, however, that mild commissural

### Discussion

In the present study, we have confirmed that development of significant MR was not infrequent after PMV in a selected group of patients with relatively low total echocardiographic scores, and that the development of significant MR did not necessarily result in severe adverse hemodynamics that required MVR. Echocardiography was used to delineate the mechanisms by which MR developed in these patients, including commissural MR, chordae rupture, and leaflet laceration. Echocardiographic determination of MR is a powerful prognostic tool, and patients with commissural MR showed more favorable prognosis with lower prevalence of MVR after PMV compared with those with noncommissural MR. The assessment of hemodynamic improvement is also important, because mean mitral gradient measured by echocardiography immediately after PMV is another independent prognostic factor.

### MR After PMV

MR occurs in up to 50% of patients after PMV, but in most cases the regurgitation is mild and only minimally detracts from the hemodynamic improvement provided by the relief of mitral valve obstruction. Severe MR, however, which frequently requires intensive medical therapy and surgery,
MR represents successful and complete commissurotomy or commissural splitting that shows higher restenosis-free survival and larger mitral valve area during follow-up. Although the mechanism by which commissural MR maintains the initial gain in mitral valve area is unclear, it is not necessarily mild. In the present study, we found that commissural MR was the most common mechanism of significant MR after PMV.

The clinical course of patients with significant MR after PMV has been reported to be variable. For example, of 15 patients, 9 remained clinically improved and free of any significant left ventricular enlargement during 11.4±4 months follow-up, whereas 6 patients (38%) underwent MVR. During a 6-month follow-up period, 71% (15 of 21) of patients underwent MVR, and 4 patients showed a decrease of MR at a mean follow-up interval of 18±5 months. In the present study, with much longer mean follow-up (>7 years), 19 patients (40%) underwent MVR, and 17 patients showed a decrease of MR. Although the differences among studies may be caused by different patient populations and different inclusion criteria for significant MR, the real clinical issue is the ability to predict or assess the probability of MVR for significant MR after PMV: atrial fibrillation, noncommissural MR, and higher mean mitral gradient immediately after PMV.

It was quite interesting to see that the mean mitral gradient itself was an independent factor. Traditionally, development of significant MR was accepted as one of the criteria for unsuccessful PMV. However, as patients with significant MR after PMV can have low mean mitral gradient and, thus, minimal symptoms without MVR, the definition of procedural success may require modification. The hemodynamic improvement provided by the relief of mitral valve obstruction should thus become the key element in the evaluation of the impact of the procedure. In addition, the development of significant commissural MR, especially in patients with low mean mitral gradient immediately after PMV, should not be considered to represent a grave prognosis.

Limitations of the Study

Although we found that the mechanism of MR was an important independent factor in determining the prognosis in patients with significant MR after PMV, the reasons that patients with commissural MR showed a better long-term event-free survival rate compared with those with noncommissural MR could not be explained completely. Patients with commissural MR showed a milder degree of MR immediately after PMV and a higher prevalence of MR decrease during follow-up. This may indicate that tearing or laceration along the natural planes of leaflet coaptation, the commissural line, is more beneficial than tearing through nonanatomic or unphysiological planes. Another limitation is that the present study was done at a single center and was not blinded. Many groups now perform transthoracic echocardiography during the procedure to assess MR. Although performance of stepwise inflations was reported to have no advantage to prevent this complication, the impact of the different techniques needs to be further investigated. Finally, as semiquantitative criteria were used to define significant MR in the present study, the impact of truly quantitative indices including effective regurgitant orifice area also remains to be elucidated.

Conclusions

The development of significant MR does not necessarily mean failure of PMV or a grave prognosis. The natural history of patients with significant MR is quite variable, and a significant proportion can tolerate their condition without MVR. Thorous echocardiographic evaluation of the mechanism of MR and hemodynamic assessments, which includes mean mitral gradient immediately after PMV, can provide important prognostic information for patient care.

Disclosures

None.

References

Development of significant mitral regurgitation (MR) after percutaneous mitral valvuloplasty (PMV) has emerged as a serious complication and is regarded as failure of PMV. However, the mechanisms of MR and clinical tolerance to immediately produced significant MR are reported to be variable. The incidence of significant MR was 12.4% (47 of 380 patients) in our study. The most frequent mechanism was commissural MR, or MR that originated at the site of successful valvulotomy, which occurred in 57% of the patients, whereas noncommissural MR occurred in 43% patients, 26% with subvalvular damage resulting in chordae rupture and flail motion and 17% with leaflet laceration. Patients with commissural MR showed significantly higher 8-year event-free survival rate (63 ± 11% versus 29 ± 11%, P < 0.001) and lower rate of mitral valve replacement (15% versus 70%, P < 0.001) compared with those with noncommissural MR. Mean mitral gradient immediately after PMV was another independent factor associated with mitral valve replacement. Clinical outcome for patients with significant MR after PMV varied according to MR mechanism and the adequacy of hemodynamic improvement. Development of significant MR due to tearing or laceration along the natural planes of leaflet coaptation, the commissural line, might be an acceptable result, as far as the hemodynamic improvement provided by the relief of mitral valve obstruction is accompanied by low mean mitral gradient after PMV.
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_Circulation_. 2006;114:2815-2822; originally published online December 11, 2006;
doi: 10.1161/CIRCULATIONAHA.106.658088
_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2006 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

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