Impact of Subvalvular Procedure for Ischemic Mitral Regurgitation on Leaflet Configuration, Mobility, and Recurrence

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Background  Procedures on the subvalvular apparatus are an etiology-based treatment for ischemic mitral regurgitation (IMR).

Methods and Results  Fifty-nine patients with IMR were divided into 3 groups: mitral annuloplasty (MAP) (M group, n=27), MAP+left ventricular reconstruction (LVR) (LV group, n=18), and MAP+LVR+subvalvular procedure (S group, n=14). Tenting height and area, angle between the annular line and the line connecting leaflet base to the bending- or tip-point of either the anterior or posterior leaflet, and leaflet mobility were measured echocardiographically preoperatively and at immediate- and mid-term postoperative follow-up. The angles at the bending-point of the anterior leaflet in mid-systole remained greater than those at its tip-point in the M and LV groups, but became significantly smaller postoperatively only in the S group (p<0.05). Postoperative leaflet mobility at the bending-point in the S group became significantly greater than in the other groups (p<0.01). The grade of MR, after significant reduction by the procedure, increased again in the M and LV groups, but remained almost unchanged in the S group.

Conclusion  Subvalvular procedures improved the configuration and mobility of the anterior leaflet, and can be expected to reduce the recurrence of IMR. (Circ J 2008; 72: 1737-1743)

Key Words:  Ischemic mitral regurgitation; Recurrence; Subvalvular procedure

Ischemic mitral regurgitation (IMR) is currently believed to mostly originate not from leaflet pathology but rather from problems with the subvalvular apparatus, including the left ventricle. Mitral annuloplasty (MAP) using an undersized ring represents the gold standard for IMR, with favorable early and intermediate postoperative outcomes. However, it is still controversial whether MAP alone is enough to control mitral regurgitation (MR) at late follow-up, because of progressive left ventricular (LV) dilatation and displacement of the subvalvular apparatus.

In contrast to MAP, which mainly increases the coaptation zone and reduces MR at the annular level, subvalvular procedures are an etiology-based strategy to correct the subvalvular anatomical changes in IMR and thus reduce the tethering force on the mitral leaflets. Subvalvular procedures are roughly classified by their target site of the pathological subvalvular apparatus: chordal cutting, papillary muscle approximation, and relocation of displaced papillary muscles. In this study, we investigated the impact of supplemental subvalvular procedures on mitral valve configuration and mobility, as evaluated by leaflet angles, and on MR at mid-term follow-up.

Methods  Fifty-nine consecutive patients with IMR who underwent surgical intervention in the past 6 years were included in this study. The patients were divided into 3 groups according to the operative procedure: MAP (M group, n=27), MAP+LVR reconstruction (LV group, n=18), and MAP+LVR+subvalvular procedure (S group, n=14). Mid-term postoperative echocardiography was completed in 26, 16, and 12 patients in the M, LV, and S groups, respectively. Our current surgical strategy for patients with ischemic heart disease is as follows. Step 1: When the patients have even a single episode of more than moderate MR, MAP with coronary artery bypass grafting (CABG) is indicated. Otherwise, the patients undergo isolated CABG. Step 2: When patients undergoing MAP have a history of previous heart failure, a LV end-diastolic volume index >90 ml/m², and LV ejection fraction (EF) <40%, LVR is indicated. Step 3: When patients undergoing LVR are diagnosed as having a great contribution of the subvalvular apparatus to the increased tethering force and consequent “sea-gull” deformity of the anterior mitral leaflet (AML) on echocardiography, 1 or 2 of the subvalvular procedures are indicated.

The study was approved by the institution’s review board and informed consent was given by all patients.
Surgical Technique

All operations were performed by a single surgeon (R.S.). Complete coronary revascularization, using as many arterial grafts as possible, was performed in all patients. With respect to the selection of the ring for MAP, our practice has been to use the Carpentier-Edwards (CE) classic or the ‘physio’ ring (Edwards Lifescience, Irvine, CA, USA) more often when the preoperative MR grade is more than moderate, and to use the flexible linear reducer when MR is less than moderate. We did not intentionally perform MAP with undersized rings, because the evidence-based significance of using undersized rings has not been established yet. We selected 1 of 3 LVR procedures, including the Dor procedure, the septal anterior ventricular exclusion (SAVE) procedure, and the overlapping procedure, for cases of septal infarction, and the Batista procedure or linear closure for cases of posterior infarction. The Dor procedure was performed during the initial 2 years of the study period and then replaced by the SAVE or overlapping procedure. The selection of the SAVE or overlapping procedure depended on the expected residual LV volume after exclusion of the non-viable infarcted myocardium during the operation.

A subvalvular procedure was indicated by the findings on preoperative transthoracic and transesophageal echocardiography. Chordal cutting is the division of a couple of secondary or basal chordae to make a bent leaflet reverse.5,6 Chordal cutting was indicated in cases with a greater contribution of tethered chordae to the increased tenting height (TH) and tenting area (TA). Papillary muscle approximation attaches both papillary muscles side by side by securing a couple of sutures placed between the bodies of both papillary muscles and was performed when the interpapillary muscle distance became wider because of LV remodeling.7,8 Papillary muscle elevation is selective relocation of the posterior papillary muscle by localized LV plication and was indicated in cases of transmural inferior infarction.9

Measurement on Echocardiography

Patients underwent transthoracic echocardiography using commercially available scanners (ATL HDI 3000, Bothell, WA, USA; Toshiba SSH 380A, Tokyo, Japan; Philips Medical Systems Sonos 5500, Andover, MA, USA; Aloka SSD-5500, Tokyo Japan; Siemens Sequoia 512, Mountain View, CA, USA) within 1 week before operation, 1–2 weeks after the operation, and at least 3 months following the operation. The TH was defined as the distance between the annulus and the end of the zone of coaptation. The TA was defined as the area outlined by the annulus and leaflets. The TH and TA were calculated in mid-systole using the 4-chamber view. Leaflet configuration and mobility were assessed in the parasternal long-axis view in mid-systole and early diastole. The angle between the annular line and a line connecting leaflet origin at annulus to the bending- or tip-point of each leaflet was measured (Fig 1). Its bending-point was regarded as an attachment site of secondary chordae and the tip-point as an attachment site of marginal chordae. The leaflet mobility was assessed by the difference between the angles at the early diastolic and mid-systolic phases of each point of the AML or posterior mitral leaflet (PML). The grade of MR was assessed qualitatively as none (grade 0), mild (grade 1), moderate (grade 2), moderately severe (grade 3), and severe (grade 4) during the initial 2 years, but was replaced by semiquantitative grading by the ratio of the MR color flow jet area to the left atrial area (mild: ratio <20%; moderate: 20–40%; moderately severe: 40–50%; severe: >50%).

Intra- and Interobserver Variabilities

To assess the intra- and interobserver variabilities, 2 observers undertook echocardiographic measurements in 10 randomly selected patients and each of them performed the same measurements in the same patients the following month.

Statistical Analysis

Data are presented as mean±standard deviation of the mean. Comparisons of preoperative variables were performed by 1-way analysis of variance (ANOVA) followed by the Student’s t-test. Statistical comparisons of continuous data among stages in each group were performed by repeated measure of ANOVA, followed by Fisher’s least significant difference as a post-hoc test. A p-value <0.05 was considered statistically significant.

Results

Patients’ Characteristics

The patients’ characteristics are presented in Table 1. The LV volume was greatest and LVEF was lowest, but not significantly, in the S group. A CE ring was used more frequently in the S group than in the M and LV groups. The size and number of the CE rings were as follows: 26 mm (6), 28 mm (5), 30 mm (2), and 32 mm (2) in the M group; 26 mm (1), 30 mm (1), and 32 mm (1) in the LV group; 26 mm (5), 28 mm (6), and 30 mm (1) in the S group. Concomitant procedures, including tricuspid annuloplasty and the Maze procedure, were more frequently performed in the S group. The interval between the operation and mid-term postoperative echocardiography was significantly shorter in the S group (9.3±5.9 months) than in the M (22.5±13.4 months) or LV (24.2±13.1 months) group (p=0.004).

TH and TA

The TH and TA in the 3 groups at the preoperative, immediate- and mid-term postoperative stages are presented in Fig 2. The preoperative TH (p=0.017) and TA (p<0.001) in the S group were significantly greater than those in the M
The TH and TA significantly diminished immediately after the operation (p<0.0001), but were slightly increased at the mid-term postoperative stage in all 3 groups. There was no significant difference between the 3 groups in the TH and TA at both the immediate and mid-term postoperative stages.

**Leaflet Angles**

The angles of the bending- and tip-points of the AML in mid-systole in the M, LV, and S groups are presented in Fig 3. The angles of the bending-point of the AML remained significantly greater than those of the tip-point in the M group (p<0.0001) and LV group (p<0.05) at all 3 stages. However, in contrast to the M group and LV group, the angles of the bending-point in the S group were significantly smaller than those of the tip-point at the immediate (p=0.007) and mid-term postoperative stages (p=0.025).

The angles of the bending- and tip-points of the PML are

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**Table 1 Preoperative Patient Profiles**

<table>
<thead>
<tr>
<th></th>
<th>M group (n=27)</th>
<th>LV group (n=18)</th>
<th>S group (n=14)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>67.9±8.9</td>
<td>62.1±12.3</td>
<td>60.7±12.3</td>
<td>0.084</td>
</tr>
<tr>
<td>Angina</td>
<td>13</td>
<td>12</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>CHF</td>
<td>16</td>
<td>12</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>LVDD (mm)</td>
<td>59.3±7.9</td>
<td>58.8±7.5</td>
<td>60.1±7.9</td>
<td>0.882</td>
</tr>
<tr>
<td>LVDS (mm)</td>
<td>47.9±9.6</td>
<td>47.1±10.2</td>
<td>51.2±8.7</td>
<td>0.452</td>
</tr>
<tr>
<td>LVEDVI (ml/m²)</td>
<td>86.4±29.0</td>
<td>91.4±24.6</td>
<td>108.3±38.6</td>
<td>0.101</td>
</tr>
<tr>
<td>LVESVI (ml/m²)</td>
<td>55.9±26.5</td>
<td>61.7±20.8</td>
<td>78.0±37.2</td>
<td>0.067</td>
</tr>
<tr>
<td>LVEF (%)</td>
<td>37.2±10.6</td>
<td>35.5±11.1</td>
<td>28.8±7.9</td>
<td>0.060</td>
</tr>
<tr>
<td>MR grade</td>
<td>1.8±0.7</td>
<td>1.3±0.6</td>
<td>1.6±0.5</td>
<td>0.051</td>
</tr>
<tr>
<td>CABG</td>
<td>4.0±1.0</td>
<td>3.5±1.7</td>
<td>3.0±2.0</td>
<td>0.168</td>
</tr>
</tbody>
</table>

The preoperative LVDd, LVDs, LVEDVI, and LVESVI were greater and the LVEF lower in the S group than in the other groups. LV, left ventricular; CHF, congestive heart failure; LVDd, LV diastolic dimension; LVDs, LV systolic dimension; LVEDVI, LV end-diastolic volume index; LVESVI, LV end-systolic volume index; LVEF, LV ejection fraction; MR, mitral regurgitation; CABG, coronary artery bypass grafting; MAP, mitral annuloplasty; CE, Carpentier-Edwards ring; FLR, flexible linear reducer; LVR, LV reconstruction; SAVE, septal anterior ventricular exclusion; linear, linear closure; PMA, papillary muscle approximation; PME, papillary muscle elevation; C.C., chordal cutting; TAP, tricuspid annuloplasty.
Fig 3. Angles of bending- and tip-points of the anterior mitral leaflet (AML) in mid-systole. The angles of the bending-point remained significantly greater than those of the tip-point in the M and LV groups. However, the angles of the bending-point in the S group were significantly smaller than those of the tip-point after the operation. Other abbreviations see in Fig 2. *p<0.05, **p<0.01.

Fig 4. Angles of the bending- and tip-points of the posterior mitral leaflet (PML). The angles of both points in both the mid-systolic (S) and early diastolic (D) phase increased significantly after the operation, making little difference in the angles among the 3 groups and between the 2 phase. The straight lines show the angles in mid-systole and the dotted lines are those in early diastole. Other abbreviations see in Fig 2.

Fig 5. Leaflet mobility of the AML. The mobility of the bending-points in the S group increased markedly after the operation, making a significant difference to the other groups. There was no significant difference in the leaflet mobility of the tip-point among the 3 groups. Abbreviations see in Figs 2, 3. **p<0.01, ***p<0.001.
presented in Fig 4. Straight lines represent the angles in the mid-systolic phase and dotted lines show the early diastolic phase. There was no significant difference in the preoperative angles of either the bending- or tip-point among the 3 groups. The angles of both points in both phases increased significantly after the operation (p<0.0001) beyond 100 degrees against the annular line.

Leaflet Mobility
The mobility of the AML, defined as the difference in the angles of the bending-point or tip-point between the early diastolic and mid-systolic phases is presented in Fig 5. The mobility of the bending point in the M group and LV group increased slightly after the operation. However, the mobility of the bending point in the S group increased more noticeably after the operation, making a significant difference compared with the mobility in the other groups at both the immediate postoperative stage (p<0.01) and mid-term postoperative stage (p<0.001). In contrast, there was no significant difference among the 3 groups in the leaflet mobility of the tip-point preoperatively and postoperatively.

The leaflet mobility at both the bending- and tip-points of the PML was within 10 degrees at both the immediate and mid-term postoperative stages, making no significant difference among the 3 groups (Fig 4).

MR
The change in MR grade is presented in Fig 6. The preoperative grade of MR in the M group was significantly greater than that in the LV group (p=0.020). The grade of MR was significantly reduced after the operation in all 3 groups (p<0.0001), making no significant difference among them both at either immediate- or mid-term postoperative stage. The MR grade at the mid-term postoperative stage increased significantly in the M group (p=0.027) and LV group (p=0.009), when compared with the immediate postoperative stage. However, the MR grade in the S group showed little change during postoperative follow-up.

Intra- and Interobserver Variabilities
The average difference in the measurements of TH and TA, and the angle in the bending-point of the anterior leaflet at mid-systole for intraobserver variation was 0.27 mm, 0.004 cm², and 1.77 degrees (r=0.891, r=0.977, and r=0.878), respectively. The average difference in the same measurements for interobserver variability was 0.06mm, 0.02 cm², and 0.67 degrees (r=0.800, r=0.925, and r=0.904), respectively.

Discussion
Recurrence of IMR in the early postoperative phase after repair is a serious issue that can have a great impact on the long-term survival of the patient. It may potentially accelerate LV dilatation and further increase the tethering force, creating a vicious cycle. McGee et al showed a relatively high incidence of IMR recurrence, even in the early stage after MAP, which was not affected by the different type of annuloplasty ring? Mihaljevic et al showed that supplemental MAP to CABG failed to improve the long-term survival of patients with moderate to severe IMR, when compared with CABG alone. Those latest reports postulated possible limitations of MAP alone as the surgical procedure of choice for IMR originating from subvalvular disorders. For better control of IMR, new generation annuloplasty rings have been developed recently, with favorable short-term results. These rings are designed on the basis of the tethering-induced characteristic deformity of the mitral leaflets. The longer-term benefit of these newly-developed rings on recurrence of IMR is now under investigation.

LV remodeling can cause LV dilatation and IMR simultaneously, which can accelerate each other in a self-perpetuating manner. The presence of MR increases the early and late mortality of patients with ischemic cardiomyopathy; Dor presented the original procedure of LVR for cases of end-stage ischemic cardiomyopathy and the Dor procedure is the gold standard treatment of LVR. Other new types of LVR procedures, including the SAVE and overlapping procedures, have been developed, with the aim of excluding broader non-viable myocardium and creating a more elliptical LV. Because of the aforementioned nature of LV remodeling, we often perform LVR and MAP simultaneously, and pay more attention to the additional effect of tethering-reduction by the following modifications of LVR. We make the patch as narrow as possible to exclude non-viable myocardium in the SAVE procedure, and make the lateral LV wall at the level of papillary muscles more overlapping of the septum in the overlapping procedure. Reduction of the distance between papillary muscles as a consequence of excluding non-viable myocardium by these modifications of the SAVE and overlapping procedures is expected to reduce the tethering force on the mitral leaflets simultaneously. However, in our present study, there was no significant additional benefit of such tethering-reduction LVR over MAP alone with respect to changes in TH, TA, angle of both mitral leaflets, and MR grade, probably because reduction of the anterior curvature between papillary muscles by the SAVE or overlapping procedure may have an indirect and insufficient effect on diminishing the interpapillary muscle distance in the posterior curvature, when compared with other direct procedures such as papillary muscle approximation. We believe that even such minor technical modifications for reducing the tethering force would be better performed simultaneously to attenuate the risk of IMR recurrence unless they would
increase operative risks.

Several subvalvular procedures designed to reduce tethering forces in addition to MAP have been reported, including second-order chordal cutting, papillary muscle imbrication, papillary muscle sling, and selective posterior papillary muscle relocation. It is our practice to perform 1 or 2 subvalvular procedures, depending mainly on the findings of preoperative transthoracic and transesophageal echocardiography, including the configuration of the mitral leaflets, the morphology of the tethered chordae, and displacement of the papillary muscle, as well as the ventricular wall underlying it.

Magne et al showed that a preoperative angle of the PML greater than 45 degrees was the best predictor of MR recurrence after restrictive MAP. In the present study, there was no significant difference in the preoperative angles of the bending- and tip-points of the PML among the 3 groups. It is more noteworthy that these angles of the PML after operation in all 3 groups were over 100 degrees and had quite small differences between the mid-systolic and early diastolic phases. These data suggest that the PML had lost its mobility throughout the cardiac cycle and faced the AML like an oblique wall, keeping a dull angle against the annulus line. These hypotheses are supported by some authors who describe the configurational change of PML after MAP. Under these conditions of the PML, the importance of the configuration and mobility of the AML must be inevitably enhanced to make inter-leaflet coaptation better and thus prevent recurrence of IMR.

One of the most striking results from our study was that supplemental subvalvular procedures corrected the preoperative “seagull” configuration of the AML and turned its concave shape to convex toward the left atrium. In addition, the mobility of the bending-point of the AML was significantly improved by the subvalvular procedures. Both effects of the subvalvular procedures are expected to increase the coaptation zone in the rough zone of the AML during systole and to avoid leakage in the later stage when the PML will be further tethered by progressive LV remodeling. The present results are compatible with those of Borger et al showing that chordal cutting significantly reduced the TA and increased the mobility of the AML, associated with a lesser incidence of IMR recurrence.

Another significant result from this study was that the subvalvular procedures remarkably reduced MR and maintained the MR grade at a low level in the mid-term postoperative stage, effectively preventing recurrence of IMR. Kongsaeerpong et al showed that a higher TA with a cut-off value of 1.6 cm² was a significant echocardiographic predictor of the recurrence of IMR. The majority of patients in the present S group had a preoperative TA >1.6 cm², but recurrence of MR was not evident in the mid-term postoperative stage.

Study Limitations
First, this was not a prospective randomized study. Second, the number of the patients was not large, and the observation period was not long enough to draw definitive conclusions. A significant difference in the observation period among the 3 groups was inevitable because the concept of a subvalvular procedure was not applied initially and most subvalvular procedures were performed in the last 2 years of the study period. Third, different types of MAP, LVR, and subvalvular procedures were included in the same groups. Lastly, preoperative quantitative evaluation of MR grade using proximal isovelocity surface area and vena contracta is now routine practice, but was not performed in this series. Nevertheless, we believe that the present study does highlight some beneficial effects of subvalvular procedures on postoperative leaflet configuration and mobility, with a potential beneficial impact on the recurrence of IMR.

References


