Restrictive Mitral Annuloplasty With or Without Surgical Ventricular Restoration in Ischemic Dilated Cardiomyopathy With Severe Mitral Regurgitation

Yasuhiro Shudo, MD; Kazuhiro Taniguchi, MD, PhD; Koji Takeda, MD, PhD; Taichi Sakaguchi, MD, PhD; Toshihiro Funatsu, MD, PhD; Hajime Matsue, MD, PhD; Shigeru Miyagawa, MD, PhD; Haruhiko Kondoh, MD, PhD; Satoshi Kainuma, MD; Koji Kubo; Seiki Hamada, MD, PhD; Hironori Izutani, MD, PhD; Yoshiki Sawa, MD, PhD

Background—We assessed changes in left ventricular (LV) volume and function and in regional myocardial wall stress in noninfarcted segments after restrictive mitral annuloplasty (RMA) with or without surgical ventricular restoration (SVR).

Methods and Results—Thirty-nine patients with ischemic cardiomyopathy (ejection fraction ≤0.35) and severe mitral regurgitation (≥3) were studied before and 2.8 months after surgery with cine-angiographic multidetector computed tomography (cine-MDCT). Eighteen underwent RMA alone (RMA group) and 21 underwent RMA and SVR (RMA+SVR group). In addition to measuring conventional parameters (LV end-diastolic volume index [LVEDVI], LV end-systolic volume index [LVESVI], and LV ejection fraction), we evaluated the regional circumferential end-systolic wall stress and mean circumferential fiber shortening in both the basal and mid-LV regions using 3-dimensional cine-MDCT images. LV end-diastolic and end-systolic volume indexes were significantly greater in the RMA+SVR group than in the RMA group preoperatively, but these values did not differ significantly postoperatively. LV end-diastolic and end-systolic volume indexes decreased significantly, by 21% and 27% after RMA and by 35% and 42% after RMA and SVR, and the percent reductions in LV end-diastolic and end-systolic volume indexes were significantly larger in the RMA+SVR group. Regional end-systolic wall stress decreased and circumferential fiber shortening increased significantly in the noninfarcted regions after RMA with or without SVR.

Conclusions—RMA plus SVR showed a potentially greater reduction of LV end-diastolic and end-systolic volume indexes than RMA alone. In selected patients with more advanced LV remodeling, concomitant SVR may favorably affect the LV reverse-remodeling process induced by RMA. (Circulation. 2011;124[suppl 1]:S107–S114.)

Key Words: tomography ■ cardiomyopathy ■ mitral regurgitation ■ left ventricular remodeling ■ stress

Progress in understanding the intrinsic ventricular architecture during postinfarction remodeling and the introduction of valuable modifications to classic left ventricular (LV) aneurysm repair have extended the indication for surgical ventricular restoration (SVR) to include more-dilated ventricles with akinetic as well as regional dysfunction. Several studies have shown that SVR is effective and relatively safe, with a favorable 5-year outcome, although whether SVR improves the effectiveness of coronary artery bypass grafting (CABG) is debated. SVR is frequently combined with restrictive mitral annuloplasty (RMA), and the impact of the combined procedure in patients with heart failure has been the subject of several recent studies. The role of concomitant SVR at the time of RMA is still controversial, and no clear guidelines exist. The acute hemodynamic improvement induced by SVR may depend on a complex interplay of changes in LV geometry and LV wall stress. Although RMA is frequently combined with SVR, the changes in regional myocardial wall stress in noninfarcted segments induced by the combined surgery have not been investigated sufficiently.

Multidetector computed tomography (MDCT) is an emerging technique that enables faster temporal resolution and more accurate contour definition. With ECG-gated image acquisition, cardiac MDCT shows different planes of the whole heart and enables the assessment of 3-dimensional volume and ejection performance. Recently, we have developed MDCT-based analysis software for computing local circumferential myocardial stress.

The objective of the present study was to assess changes in LV volume and function and in regional myocardial stress in noninfarcted segments before and after RMA with or without SVR.
Thirty-nine patients with ICM and functional MR (grade 3 or greater) were referred for surgery. All had congestive heart failure symptoms, a history of at least 1 hospitalization, anterior/anteroseptal myocardial infarction, and advanced LV remodeling as defined by an LV ejection fraction (LVEF) $\leq 0.35$ and an end-systolic volume $>120$ mL on preoperative left ventriculography. We excluded patients whose LV remodeling was less advanced or whose "ischemic" MR was secondary to a regional LV deformity caused by wall thinning or other nonischemic process. Of the 39 patients enrolled, 18 underwent RMA alone (RMA group), and the remaining 21 underwent RMA and concomitant SVR (RMA+SVR group). SVR was performed when broad anterior or anteroseptal akinesis or dyskinetic wall motion with wall thinning was detected by echocardiography. Selection between SVR procedures was based primarily on the preference of the surgeons (K. Taniguchi and T.S.). Coronary artery disease was treated either with CABG or percutaneous coronary intervention before surgery. Postoperative MR was none or trivial in all patients.

For comparative purposes, 38 subjects (26 men, 12 women; age range 49 to 82 years, mean 66+11 years) who did not have significant valvular or congenital cardiac disease, history of myocardial infarction, coronary artery lesions, or abnormal findings by echocardiography volunteered to participate in the study. Our institutional ethics committee approved this study, and written informed consent for all procedures was obtained from all patients before surgery.

**Surgical Procedures**

Surgeries were performed through a median sternotomy under mild hypothermic cardiopulmonary bypass with antegrade and retrograde intermittent cold blood cardioplegia. All patients underwent a stringent RMA (2 to 4 ring sizes smaller than measured; Table 2) with a Fontan stitch to eliminate anterior/anteroseptal dyskinetic wall motion with wall thinning. Simultaneous CABG nearly always involved grafting the left internal thoracic artery to the left anterior descending artery.

**Methods**

**Patients**

Thirty-nine patients with ICM and functional MR (grade 3 or greater) were referred for surgery. All had congestive heart failure symptoms, a history of at least 1 hospitalization, anterior/anteroseptal myocardial infarction, and advanced LV remodeling as defined by an LV ejection fraction (LVEF) $\leq 0.35$ and an end-systolic volume $>120$ mL on preoperative left ventriculography. We excluded patients whose LV remodeling was less advanced or whose "ischemic" MR was secondary to a regional LV deformity caused by inferior/posterior myocardial infarction, or who had organic MR, a rheumatic mitral valve, or aortic valve disease. All patients were receiving optimized medical regimens, including $\beta$-blockers, angiotensin-converting enzyme inhibitors or angiotensin-receptor blockers, and diuretics. There were no significant between-group differences with respect to age, sex, body surface area, New York Heart Association (NYHA) functional class, LV dimension, or frequency of medical conditions listed, as shown in Table 1.

**Cine-MDCT Angiography, Image Acquisition, and Data Processing**

ECG-gated MDCT examinations of the heart were performed 1 month before surgery and repeated an average of 2.8 months (range 1.4 to 5.0 months) after surgery with a commercially available 64-slice multidetector scanner (SOMATOM Definition Dual Source CT, Siemens, Germany). No premedication with $\beta$-blockers to reduce the heart rate was used. Scans were performed during a single breath hold and lasted approximately 6 to 10 seconds or less. Patients were instructed to maintain an end-inspiratory breath hold, and data acquisition was begun.

Computed tomographic data of the entire heart were reconstructed with retrospective ECG gating and a standard cardiac algorithm.
LV Pressure Estimation
Blood pressure was obtained by a digital sphygmomanometer before the MDCT examinations. The LV end-systolic pressure (LVESP) was calculated for patients without significant MR (≥3+/4+) as LVESP = 1.0 × mean arterial cuff pressure + 7 mm Hg and estimated in patients with significant MR as LVESP = 0.98 × mean arterial cuff pressure + 11 mm Hg.11

Assessment of Regional Myocardial Wall Stress
The imaging analysis to assess regional myocardial stress was performed on a personal computer with dedicated analysis software (Osaka University-OSCAR STRESS tool, Osaka, Japan). LV end-diastolic volume, LV end-systolic volume, and LVEF were measured according to the slice summation method by manually drawing the endocardial and epicardial contours of short-axis images. LV volumes were indexed for body surface area. Intraobserver variability (Y. Shudo) and interobserver variability (Y. Shudo versus K. Takeda) for LVEDVI, LVESVI, and LVEF were evaluated with images obtained from 20 subjects.

The imaging analysis to assess regional end-systolic wall stress (ESS) was performed on a personal computer with dedicated analysis software for myocardial stress estimation. The software can measure regional ESS along 100 chords evenly spaced along the epicardial border in each image (Figure 1). In the present study, to simplify the display and analysis of regional ESS, 3 LV levels (base, mid-LV, and apex) were determined with reference to the long axis, and 3 perpendicular short axes were set at equal intervals. The regional ESS in the apical infarcted level was excluded from the present study because this region might be excluded by SVR. Regional ESS was calculated by averaging the value at consecutive local chords within each level.

Regional ESS was computed with the Janz formula (Equation 1) as12:

\[
\text{Regional ESS} = \frac{P \times \Delta A_c}{\Delta A_w}
\]

where P is end-systolic pressure, ΔA_c is the cross-sectional area of the LV cavity, and ΔA_w is the cross-sectional area of the LV wall at end systole in each long-axis plane. The wall cross-sectional area was defined as the area bounded by the 2 lines perpendicular to the cavity surface.9 The average values of regional ESS for each element, eg, basal or mid-LV short-axis slice, were then calculated for each patient.

For regional analysis of circumferential shortening, the 3 circular (basal, midcavity, and apical) short-axis slices of the LV were subdivided into 2 equal semicircular slices at the middle plane of each slice. The mean circumferential fiber shortening (CFS) was determined with the following equation:

\[
\text{Mean CFS} = \frac{(\text{EDD} - \text{ESD})}{\text{EDD}}
\]

where EDD is the end-diastolic short-axis dimension and ESD is the end-systolic short-axis dimension. The regional mean endocardial CFS was measured across the middle of each short-axis slice.

Echocardiography
Standard 2-dimensional and Doppler echocardiographic examinations with color-flow mapping were performed serially on all patients 1 week before and 2.0 months after the operation (GE Medical Systems, Vivid 7, Milwaukee, WI). Color-flow imaging was used to determine the presence or absence of MR, and the degree of MR was graded as follows based on the color Doppler echocardiography results at end systole: None to trivial (0 to 1+), mild (2+), moderate (3+), or severe (4+).13 All echocardiographic data were analyzed in random order by trained readers who were blinded to the clinical data and timing of the echocardiogram.

Follow-Up
Patients were followed up in the hospital or outpatient clinic (by their primary cardiologist) at intervals of 3 to 6 months. The mean follow-up period for all patients was 685 days (range 75 to 1641 days). All 39 patients completed the follow-up examinations, which concluded on April 30, 2010. Although the follow-up period varied depending on the patient, there was no significant difference in the mean follow-up period between the 2 study groups (P = 0.76). The NYHA functional class and the clinical outcomes of death due to any cause or hospitalization for cardiac causes were recorded. The medical records of these patients were reviewed retrospectively for preoperative and postoperative data, and current information was obtained by interviewing the patient or the referring cardiologist.
Table 3. Hemodynamics and Left Ventricular Measurements

<table>
<thead>
<tr>
<th>Variables</th>
<th>Controls (n=38)</th>
<th>RMA (n=18)</th>
<th>RMA + SVR (n=21)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preoperative</td>
<td>Postoperative</td>
<td>Δ</td>
</tr>
<tr>
<td>Heart rate, bpm</td>
<td>67±12</td>
<td>74±12</td>
<td>74±10</td>
</tr>
<tr>
<td>Brachial artery pressure, mm Hg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td>127±19</td>
<td>106±27†</td>
<td>113±20† NC</td>
</tr>
<tr>
<td>Diastolic blood pressure</td>
<td>70±12</td>
<td>64±11†</td>
<td>63±9† NC</td>
</tr>
<tr>
<td>Mean arterial pressure</td>
<td>89±13</td>
<td>78±18†</td>
<td>79±13† NC</td>
</tr>
<tr>
<td>End-systolic pressure</td>
<td>97±13</td>
<td>87±18†</td>
<td>86±13† NC</td>
</tr>
<tr>
<td>Global LV volume, mL/m²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVEDVI</td>
<td>60±16</td>
<td>137±54†</td>
<td>108±31† −29±31</td>
</tr>
<tr>
<td>LVESVI</td>
<td>21±8</td>
<td>99±42†</td>
<td>72±31† −27±28</td>
</tr>
<tr>
<td>Global and regional systolic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>performance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVEF</td>
<td>0.65±0.07</td>
<td>0.27±0.08†</td>
<td>0.35±0.10† 0.08±0.10</td>
</tr>
<tr>
<td>Basal average CFS, circ⁻¹</td>
<td>0.38±0.05</td>
<td>0.15±0.04†</td>
<td>0.18±0.04† 0.03±0.02</td>
</tr>
<tr>
<td>Mid-LV average CFS, circ⁻¹</td>
<td>0.40±0.06</td>
<td>0.15±0.03†</td>
<td>0.17±0.03† 0.02±0.02</td>
</tr>
<tr>
<td>Regional circumferential end-systolic wall stress, kdyn/cm²</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basal ESS</td>
<td>186±56</td>
<td>308±110†</td>
<td>210±66* 98±120</td>
</tr>
<tr>
<td>Mid-LV ESS</td>
<td>170±57</td>
<td>287±86†</td>
<td>227±75† 60±81</td>
</tr>
</tbody>
</table>

RMA indicates restrictive mitral annuloplasty; SVR, surgical ventricular restoration; Pre, preoperative; Post, postoperative; Δ, postoperative value minus preoperative value; bpm, beats per minute; NC, not calculated; LV, left ventricular; LVEDVI, left ventricular end-diastolic volume index; LVESVI, left ventricular end-systolic volume index; LVEF, left ventricular ejection fraction; CFS, circumferential fiber shortening; and ESS, end-systolic circumferential myocardial stress.

Data are presented as mean ± SD.

*P<0.05 for patients before vs after surgery.
†P<0.05 vs control.
‡P<0.05 for patients in RMA group vs patients in RMA + SVR group.

Statistical Analysis

SPSS (version 16.0, SPSS Inc) software was used for statistical analyses. Continuous values are expressed as mean ± SD or mean value. Normally distributed variables were compared with Student t test for paired or unpaired data, and nonnormally distributed variables were compared by the Wilcoxon signed rank test or the Mann-Whitney U test. The MDCT-derived parameters (ie, LVEDVI, LVESVI, LVEF, CFS, and ESS) were analyzed over time with repeated-measures ANOVA. Categorical variables were analyzed by a χ² test or Fisher’s exact test. Intraobserver and interobserver variabilities in the measurements of LV end-diastolic volume, LV end-systolic volume, and LV EF were analyzed by linear regression analysis. P<0.05 was considered statistically significant.

Results

Clinical Results

All patients tolerated the operation well. Mean NYHA functional class was significantly improved, from 3.0±0.6 to 2.0±0.8 (P<0.001). Mean NYHA functional class did not differ between the 2 groups (P=0.36 preoperatively and 0.73 postoperatively). During follow-up, 2 (11%) of 18 patients in the RMA group and 3 (14%) of 21 patients in the RMA + SVR group had recurrent congestive heart failure symptoms of NYHA functional class III or IV. The other patients remained well, with NYHA class I or II. The degree of MR was <2+ in all patients, a significant decrease (from 3.4±0.5 to 0.6±0.8; P<0.0001). During a mean follow-up of 23 months, the clinical outcome of death of any cause or hospitalization for cardiac causes occurred in 1 (5%) of 21 patients in the RMA group because of worsening congestive heart failure (n=1) and in 2 (11%) of 18 patients in the RMA + SVR group because of worsening congestive heart failure (n=1) and septic shock after infective endocarditis (n=1).

Intraoperative data are presented in Table 2. There were no significant differences in cardiopulmonary bypass time or aortic cross-clamp time between the 2 groups (P=0.35 and P=0.55, respectively). There were also no between-group differences in the type or size of the annuloplasty device used or the number of concomitant procedures (P>0.05 for all).

Heart Rates and Blood Pressure Measurements

As shown in Table 3, heart rates did not differ between the study groups and did not change postoperatively. Neither the preoperative nor the postoperative heart rates in the study groups differed from those in the controls.

Systolic and diastolic blood pressures and mean arterial and end-systolic pressures in both study groups did not change postoperatively (Table 3). These blood pressures in the study groups both preoperatively and postoperatively were significantly lower than those in the controls.

LV Volumes

LV end-diastolic and end-systolic volume indexes (LVEDVI and LVESVI, respectively), which were markedly higher in both study groups preoperatively than in the controls (P<0.0001 for both), decreased significantly after surgery (P<0.0001 for both) but were still significantly higher than in the controls (P<0.01 for both; Table 3). Preoperative LVEDVI and LVESVI were significantly greater in the
Global and Regional Systolic Performance

Global LVEF, which was severely impaired in both study groups preoperatively, showed a significant increase postoperatively (P<0.001, respectively; Table 3). Global LVEF in the study groups both preoperatively and postoperatively was significantly lower than in the controls (P<0.01, respectively). There was no significant difference between the 2 study groups (P>0.05 both preoperatively and postoperatively; Figure 2).

The mean regional CFS in both the basal and mid-LV regions, which was reduced in both study groups preoperatively compared with controls (P<0.001, respectively), also increased significantly postoperatively (P<0.001, respectively) but was still significantly lower than in the controls (P<0.01, respectively). There was no significant difference in either region between the 2 study groups (P>0.05 for all).

Regional Circumferential ESS

Preoperatively, regional ESS was markedly elevated in both the basal and mid-LV regions of the LV in both the RMA and RMA+SVR groups compared with the corresponding regions in the controls (P<0.001, respectively; Table 3). At the basal region, regional ESS decreased significantly by an average of 142 kdyne/cm², from 359 to 217 kdyne/cm² (a reduction of 39%) in the RMA+SVR group, and by an average of 98 kdyne/cm², from 308 to 210 kdyne/cm² (a reduction of 32%) in the RMA group. At the mid-LV region, regional ESS significantly decreased by an average of 115 kdyne/cm², from 335 to 220 kdyne/cm² (a reduction of 34%) in the RMA+SVR group, and by an average of 60 kdyne/cm², from 287 to 227 kdyne/cm² (a reduction of 21%) in the RMA group, but the values remained significantly higher for both groups than in the controls (P<0.01; Figure 3).

Magnitude of Changes in Global LV Volume, LVEF, and Regional ESS

The percent reductions in LVEDVI and LVESVI were significantly larger in the RMA+SVR group than in the RMA group: -35±20% versus -21±22% for LVEDVI (P=0.003) and -42±25% versus -27±28% for LVESVI.
different degrees of effects (Figure 4).

The present study focused on the LV volumetric change, left ventricular ejection fraction (LVEF), and regional end-systolic circumferential myocardial stress (ESS) in the basal and mid-left ventricular (mid-LV) regions in patients in the restrictive mitral annuloplasty (RMA; black bar) and RMA plus surgical ventricular restoration (RMA + SVR; open bar) groups. \( P < 0.05 \) between RMA group and RMA + SVR group. LVEDVI indicates left ventricular end-diastolic volume index; LVESVI, left ventricular end-systolic volume index.

\( (P = 0.006) \). The percent improvement in LVEF was significantly larger in the RMA + SVR group than in the RMA group (42\( \pm \)36\% versus 30\( \pm \)37\%, \( P = 0.01 \)).

The percent reduction of regional ESS in the basal and mid-LV regions tended to be greater in the RMA + SVR group than in the RMA group, although these differences did not reach statistical significance as of 2.8 months after the operation, which reflects the fact that the 2 procedures have different degrees of effects (Figure 4).

Discussion

The major findings of the present study are as follows: (1) LVEDVI and LVESVI were significantly greater in the RMA + SVR group than in the RMA group preoperatively, but they did not differ significantly between the 2 groups postoperatively. (2) LVEDVI and LVESVI decreased significantly, by 21\% and 27\% after RMA and by 35\% and 42\% after RMA + SVR, and the percent reductions in LVEDVI and LVESVI were significantly larger in the RMA + SVR group than in the RMA group. (3) Regional ESS and CFS improved significantly in the noninfarcted regions after RMA with or without SVR. The present findings indicated that RMA + SVR had a potentially greater effect in reducing LVEDVI and LVESVI than RMA. Although the role of concomitant SVR at the time of RMA is still controversial and no clear guidelines exist, the present results suggest that selected patients with advanced LV remodeling may benefit from concomitant RMA and SVR. The present data also suggest that regional dysfunction of the residual noninfarcted myocardium is at least partly reversible, although it is unknown whether this reversal is related to the alteration in contractility.

The present study focused on the LV volumetric change, measured by use of MDCT images, associated with RMA with or without SVR in patients with functional MR and ICM. In this small series, the addition of SVR resulted in a significantly greater degree of reduction in LV volume than was achieved with RMA alone. Although this difference might be explained by an additive effect of SVR with RMA, or as a function of the significantly greater preoperative values in this group, it is possible that this effect could contribute to the restoration of anterior/anteroseptal infarcted myocardium. In addition, our results showed that the postoperative LVEDVI and LVESVI were not different between the 2 study groups, which indicates either that SVR does not have a significant effect beyond RMA alone or that SVR is only useful in patients with a more severely dilated LV. However, future studies that control for the preoperative LV volume will be necessary to address this question. Data from a number of studies support the efficacy and use of SVR,2,7,14,15 Many of these studies have demonstrated that in selected patients with ICM, ventricular reconstruction with various techniques can be accomplished with low operative mortality, improved LV volumes and function, and improved exercise capacity, quality of life, and NYHA class, along with reduced incidents of rehospitalization and good midterm survival.2,7,14,17

The recent Surgical Treatment for Ischemic Heart Failure (STICH) trial, which was randomized, concluded that the combination of SVR with CABG results in greater clinical benefits than CABG alone.4 However, despite the larger reduction in LV end-systolic volume index obtained in their study (19\% versus 6\%),4 the findings are strongly debated, largely because the SVR-related volume reductions were much smaller than in other SVR trials (typically 40\%).18 In the present results, the LV end-systolic volume index decreased by 42\% (52\( \pm \)31 mL/mm\(^2\)) in the SVR + RMA group as of 2.8 months after the operation, which is in line with most previous studies at mid-term follow-up, for example, the RESTORE (Reconstructive Endoventricular Surgery returning Torsion Original Radius Elliptical shape to the left ventricle) group (57\( \pm \)34 mL/mm\(^2\)).2 Dor and coworkers (51\( \pm \)18 mL/mm\(^2\)),16 and Di Donate and associates (average of 3 groups: 44\( \pm \)20 mL/mm\(^2\)).17

The adverse effects of LV dilatation were codified by White and associates,19 who showed that increased ventricular volume rather than altered ejection fraction became the principal surrogate for mortality, regardless of whether the patient had significant residual coronary artery obstruction. In the present study, even when the LV was severely dilated, our approach (ie, RMA with SVR) was successful, resulting in LV volumetric reduction, wall stress reduction, attenuated LV ejection performance, improved symptoms, and satisfactory early results. These results were similar to those of RMA without SVR in patients with a less dilated LV. These findings may reflect the role of additional SVR as a surrogate for a more severe natural history of increasing morbidity and mortality in dilated hearts, although it is still unknown whether these surgical interventions improve the clinical status of the patient. Therefore, we assume that for selected patients with functional MR who have broad akinesia or dyskinesia associated with relative wall thinning, RMA with SVR is a reasonable surgical option that may prove beneficial.

Previous studies showed that hemodynamic improvement induced by SVR may depend on a complex interplay of changes in LV volume and LV wall stress.7,8 It is possible that

![Figure 4. Magnitude of changes in global left ventricular volume, left ventricular ejection fraction (LVEF), and regional end-systolic circumferential myocardial stress (ESS) in the basal and mid-LV regions in patients in the restrictive mitral annuloplasty (RMA; black bar) and RMA plus surgical ventricular restoration (RMA + SVR; open bar) groups.](http://circ.ahajournals.org/)}
reverse remodeling may happen in the border zone and induce further improvement in myocardial function. However, chronic changes in myocardial stress, especially in the noninfarcted myocardium, after RMA with or without SVR have not been fully investigated, because it can be difficult to measure regional myocardial stress in LVs with different shapes. In the present study, we attempted to assess the changes in regional myocardial stress after RMA with or without SVR in patients with ICM and functional MR. We observed that regional ESS in the noninfarcted myocardium decreased substantially after RMA with or without SVR. We also observed that regional CFS improved in the same 2 regions after surgery. The present data suggest that regional dysfunction of the residual noninfarcted myocardium may be reversible, at least in part, although whether the improvement is related to the reduction in myocardial wall stress or to an alteration in the myocardial contractile property itself still needs to be evaluated.

Recent advances in steady-state free precession sequencing for cardiac MDCT have resulted in a shorter acquisition time and improved image quality. Considering the relatively short acquisition time and adequate quality of the reconstructed images, 64-row MDCT is a useful clinical tool for assessment of the LV contour in patients with ICM and functional MR. The present study provides an additional approach for evaluation of LV volume, ejection performance, and wall stress, either globally or regionally. Echocardiography has been widely used to measure LV volume in heart failure, but the results are based on geometric assumptions that limit the accuracy of the data. Currently, cardiac magnetic resonance imaging (MRI) is considered the "gold standard" for LV geometry and volume evaluation. It provides excellent temporal and spatial resolution, along with a high degree of accuracy, and reproducible quantitative measurements. Multiphase cine imaging quality is significantly better in MRI than in MDCT because of differences in temporal resolution. However, MRI requires an extended scanning period and cannot be used for patients with a pacemaker. Previous computed tomography studies have shown a good correlation and acceptable agreement of LV volumes and cardiac function compared with MRI. This is probably because LV volumes and cardiac function are mainly determined by the end-systolic and end-diastolic phases, when cardiac motion is comparatively minimal and motion artifacts are negligible. Therefore, 64-row MDCT appears to be a useful alternative to 2-dimensional or 3-dimensional echocardiography or MRI in the present study population with metal implants (eg, pacemakers or implantable cardioversion-defibrillators), claustrophobia, or other conditions that are not suitable for MRI.

Clinical Implications
On the basis of the present results in patients undergoing RMA who have ICM and functional MR, we favor combining RMA with SVR to exert an additional LV reverse-remodeling effect. In the present study, even when the LV was severely dilated, our approach was successful, and the early results are satisfactory.

Study Limitations
The major limitations of the present study are that it was not conducted in a randomized manner and that it involved a rather small sample size. However, the 100% patient follow-up is a strength. The study would have been stronger with a larger, randomized, and controlled population. In addition, the small sample size could place the study at risk for a type II error. Because we used each patient’s preoperative data as his or her baseline, the statistical power was optimized.

Next, the preoperative LV volume differences between the 2 study groups might involve a probable selection bias toward SVR in patients with larger hearts; however, all the patients met the optimal entry criteria, which were the same as in previous studies.

Regarding the technical aspects, the variety of surgical procedures and type of annuloplasty ring could have influenced the outcomes. SVR is still not a standardized technique, however, and the optimal procedure remains to be investigated. Concomitant procedures, especially CABG, might have favorably influenced our patients’ LV functional improvements. The STICH trial report showed that in 212 patients with LVEF <35% undergoing CABG alone, the mean end-systolic volume index at 4 months after surgery had decreased by an average of 5 mL/m², from 82 to 77 mL/m² (6% reduction), which indicates that there were no measurable functional improvements in those patients. Moreover, we previously observed no significant improvements in LV volumes, regional stress, or regional CFS in the noninfarcted myocardium at 8 months after CABG alone in patients with severe LV dysfunction. Therefore, we think that the effect of revascularization could be minimized in the present results. Comparison of the fraction of patients who received concomitant CABG in each study group in the present series (RMA versus RMA+SVR; 83% versus 52%) suggests that there was little influence on LV volume, LVEF, or regional stress. However, differences may become obvious with further follow-up, because revascularization effects can be delayed well beyond 3 months in the failing ventricle. We preferably used a semirigid complete annuloplasty ring. A previous report suggests that the type of annuloplasty ring could influence the postoperative LV function; therefore, the present results would not be applicable to patients who received another type of prosthesis. Our results were obtained only from patients who underwent RMA with or without SVR, but the study did not include a control group of patients who did not have either procedure, and withholding surgery from such patients would be unethical in any case. To differentiate between the effects of RMA and SVR, future investigations that include other study groups to compare with patients undergoing SVR to treat functional MR will be required. The patients enrolled in the present study all had ICM associated with anterior or anteroseptal infarction. Therefore, the present results are not applicable to patients with inferior or lateral infarctions or patients with nonischemic dilated cardiomyopathy.

Finally, we used 64-row MDCT as the image modality. As with conventional modalities, MDCT has inherent limitations, including the need for contrast medium and radiation exposure. However, its high spatial resolution enables us to closely estimate regional wall thickness and appropriately compare preoperative values with postoperative values, which makes it particularly useful for estimating regional
myocardial stress. Moreover, given the increased use of cardiac defibrillators or biventricular pacemakers in patients with heart failure, which contraindicate some modalities (eg, MRI), MDCT should prove useful for noninvasively assessing ventricular function, although this point would have been stronger if the results could have been compared with MRI measurements.

Differences in the patients’ breath-holding positions between slices and the vertical motion of the mitral annulus can affect the reconstructed images. For this reason, we determined the LV contour by carefully obtaining data from the same plane, as much as possible, before and after surgery. Therefore, differences due to the breath-holding position in the present patient series were negligible, and 3-dimensional reconstruction of the intracardiac anatomy from a series of 2-dimensional images was feasible and clinically useful.

Conclusions
RMA with or without SVR reduced LV end-diastolic and end-systolic volume, which led to improved global ejection performance, reduced regional myocardial wall stress, and improved regional fiber shortening of the noninfarcted myocardium in patients with ICM and functional MR. We found that RMA with SVR reduced the LVEDVI and LVESVI more than RMA alone. In correctly selected patients with more advanced LV remodeling, concomitant SVR may favorably affect the LV reverse-remodeling process induced by RMA.

Acknowledgment
We wish to thank Dr Takashi Daimon, Department of Biostatistics, Hyogo College of Medicine, for his statistical assessment.

Disclosures
None.

References
Restrictive Mitral Annuloplasty With or Without Surgical Ventricular Restoration in Ischemic Dilated Cardiomyopathy With Severe Mitral Regurgitation

Yasuhiro Shudo, Kazuhiro Taniguchi, Koji Takeda, Taichi Sakaguchi, Toshihiro Funatsu, Hajime Matsue, Shigeru Miyagawa, Haruhiko Kondoh, Satoshi Kainuma, Koji Kubo, Seiki Hamada, Hironori Izutani and Yoshiki Sawa

_Circulation_. 2011;124:S107-S114
doi: 10.1161/CIRCULATIONAHA.110.010330
_Circulation_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 2011 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/124/11_suppl_1/S107

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in _Circulation_ can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to _Circulation_ is online at:
http://circ.ahajournals.org/subscriptions/