Basal Left Ventricular Dilatation and Reduced Contraction in Patients With Mitral Valve Prolapse Can Be Secondary to Annular Dilatation

Preoperative and Postoperative Speckle-Tracking Echocardiographic Study on Left Ventricle and Mitral Valve Annulus Interaction

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**Background**—Prominent mitral valve (MV) annular dilatation with only modest left ventricular (LV) dilatation in patients with MV prolapse (MVP) suggests predominant dilatation in adjacent basal LV, which may augment regional wall tension and attenuate contraction by Laplace’s law. We hypothesized that MV annular dilatation in patients with MVP is associated with the basal predominance of LV dilatation and attenuated contraction, which can be altered by surgical MV plasty with annulus reduction.

**Methods and Results**—Echocardiography with speckle-tracking analysis to assess regional cross-sectional short-axis area and longitudinal contraction (strain) of basal, middle, and apical LV was performed in 30 controls and 130 patients with MVP. The basal value/averaged middle and apical values (B/M·A ratio) of LV cross-sectional area and strain were obtained. Patients with MVP showed significantly greater MV annular area (6.4±1.6 versus 3.7±0.6 cm²/m²), increased B/M·A LV area ratio (2.4±0.5 versus 1.8±0.2), and reduced B/M·A LV strain ratio (0.83±0.14 versus 0.96±0.09) than controls (P<0.001). Multivariable analyses identified that MV annular dilatation was independently associated with increased B/M·A LV area ratio (β=0.60, P<0.001), which was associated with reduced B/M·A LV strain ratio (β=−0.32, P<0.001). In 35 patients with MVP, B/M·A LV area and strain ratio significantly altered after surgical MV plasty with annulus reduction (2.5±0.5–1.8±0.2 and 0.73±0.10–0.89±0.17, P<0.001, respectively).

**Conclusions**—In patients with MVP, MV annular dilatation was associated with the basal predominance of LV dilatation and reduced contraction, which can be altered by surgical MV plasty with annulus reduction, suggesting unfavorable influence from MV annular dilatation on basal LV. *(Circ Cardiovasc Imaging. 2016;9:e005113. DOI: 10.1161/CIRCIMAGING.115.005113.)*

**Key Words:** dilatation ▪ echocardiography ▪ left ventricle ▪ mitral valve ▪ prolapse

In addition to superior displacement of the mitral valve (MV) leaflets into the left atrium, a reduced left ventricular (LV) contraction, especially in its base, has been reported in patients with MV prolapse (MVP). However, its mechanism remains unclear.

**See Editorial by Obase and Yoshida See Clinical Perspective**

Typical patients with MVP, especially global leaflet prolapse or Barlow type prolapse, have prominent MV annular dilatation with only modest LV dilatation. This discrepancy suggests that patients with MVP and annular dilatation frequently have basal predominance of LV dilatation (Figure 1). Predominantly, basal LV dilatation may cause greater systolic wall tension in the LV base compared with the middle and apical segments by Laplace’s law, which may lead to regionally attenuated contraction in the LV base. We, therefore, hypothesized that a dilated MV annulus in patients with MVP may be related to the basal predominance of LV dilatation and reduced contraction. We further hypothesized that such basal dilatation is associated with the basal predominance of LV dilatation and attenuated contraction.
Prevalence of LV abnormality may be altered by surgical MV plasty with annular size reduction.

The no. 1 purpose of this research is to investigate relationships between basal predominance of LV dilatation with reduced contraction and MV annular dilatation in patients with MVP, and purpose no. 2 is to examine whether the basal predominance is altered by surgical MV plasty with annular size reduction. This investigation addresses a novel MV annulus and LV interaction with a potential to clarify unfavorable influence on basal LV from MV annular dilatation, which can be clinically intervened.

Methods

Study Population
Consecutive patients with MVP were recruited at the echocardiographic laboratories of 3 collaborating institutions: University of Occupational and Environmental Health (n=70), Asan Medical Center (n=34), and Sakakibara Heart Institute (n=26). MVP was defined as the presence of systolic displacement (>2.0 mm) of 1 or both MV leaflets into the left atrium above the plane of the MV annulus. The exclusion criteria were (1) association with other cardiac disease and (2) inadequate echocardiographic image. Consequently, 130 patients (78 men; mean age, 60±15 years) with MVP were included. Of the 130 patients, 35 (19 men; mean age, 60±14 years) subsequently underwent surgical MV plasty with ring implantation. Postoperative echocardiography was performed 7±5 days after the surgery. Age- and sex-matched controls included 30 healthy subjects (18 men; mean age, 60±15 years) with no history of cardiac disease or risk factors. The echocardiographic data set was sent to the University of Occupational and Environmental Health, and a single physician (S.F.) with 15 years of experience in echocardiography laboratories analyzed the data set. This study was approved by the ethics committee of each institution, and informed consent was obtained from all subjects.

General Echocardiographic Measurements
Comprehensive echocardiographic study was performed using commercially available equipments (iE-33, Philips Medical Systems, Andover, MA or Vivid 7, GE Medical Systems, Milwaukee, WI). All equipment was managed according to the guideline to derive reliable measurements. Using apical 4- and 2-chamber views, LV end-diastolic and end-systolic volumes were measured by the bpline Simpson method to calculate ejection fraction. MV annular area in midsystole was measured by the annular dimension in apical 4- and 2-chamber views with an elliptical assumption. MR volume was calculated as the difference between mitral and aortic stroke volumes. Effective regurgitant orifice area and MR volume were further quantified by proximal isovelocity surface area method in patients with surgery. Images with regular R–R intervals in the 2 preceding cardiac cycles were used for measurements in patients with atrial fibrillation.

Basal Predominance of LV Dilatation and Reduced Contraction
The LV long-axis dimension from the apex to the MV annular level in midsystole was trisected, and transverse dimensions of basal, middle, and apical LV were measured in apical 4- and 2-chamber views, respectively (Figure 2). The LV cross-sectional area at each level was then calculated by the transverse dimensions with an elliptical assumption. The ratio of basal to middle apical LV cross-sectional area (CSAB, CSAM, and CSAa, respectively) were obtained by an elliptical assumption. The basal LV area ratio, was obtained as an index to express the basal predominance of LV dilatation.

Speckle-tracking analysis was performed using a commercially available software for each vendor system: QLAB Advanced Quantification Software for iE-33 and EchoPac for Vivid 7. The standard 3 apical views were used for the analysis. Longitudinal strain value (the rate of longitudinal tissue length shortening in systole) represented systolic shortening and contraction. Peak longitudinal strain was measured in 6 basal, 6 middle, and 6 apical segments, and the average of the 18 segments was the global LV strain. Similarly, basal, middle, and apical strain was the averaged strain of 6 basal, 6 middle, and 6 apical segments, respectively. Circumferential strain was similarly analyzed in 118 patients with short-axis image recording of all the 3 apical, middle, and basal levels. Radial strain was also analyzed in 64 of the 118 patients because of the feasibility limited to GE recording. The B/M-A LV strain ratio, basal strain divided by the average of the middle and apical strain, was then obtained as an index to express the basal predominance of reduced LV contraction.

Statistical Analysis
Categorical variables were presented as frequencies and continuous variables as mean±SD. Unpaired continuous variables were compared by unpaired t test. The no. of patients with MVP who were not intervened surgically was compared with those who were intervened surgically using the chi-square test. Unpaired t test was used to compare the groups of patients with MVP who underwent MV plasty with annular size reduction.

Figure 1. Possible association of prominent mitral valve annular dilatation with basal predominance of left ventricular (LV) dilatation in patients with mitral valve prolapse (MVP). This characteristic LV geometry may cause regionally augmented wall tension with reduced contraction in the LV base by Laplace's law. LA indicates left atrium.

Figure 2. Method to measure basal predominance of left ventricular (LV) dilatation. The LV long-axis dimension was trisected and transverse dimensions of basal, middle, and apical LV were measured in apical 4- and 2-chamber views, respectively. Basal, middle, and apical LV cross-sectional areas (CSAa, CSAm, and CSAB, respectively) were obtained by an elliptical assumption. The ratio of basal to middle-apical LV cross-sectional area (CSAa/0.5x(CSAa+CSAb)) was obtained as an index to express basal predominance of LV dilatation.
Table 1. Clinical and Echocardiographic Profile

<table>
<thead>
<tr>
<th>Variables</th>
<th>MVP (n=130)</th>
<th>Controls (n=30)</th>
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<tr>
<td>Age, y</td>
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<td>60±15</td>
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<td>Sex (male/female)</td>
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<td>18/12</td>
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<td>Hyperlipidemia, %</td>
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<td>Atrial fibrillation, %</td>
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<tr>
<td>LV Peak systolic strain</td>
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<tr>
<td>Annular area, cm²/m²</td>
<td>6.4±1.6</td>
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<td>MR volume by continuity equation, mL/beat</td>
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<td>2.5±6.9</td>
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<td>Indexed MR volume by continuity equation, mL/beat</td>
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<td>Middle, cm²/m²</td>
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<td>Peak systolic strain</td>
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<tr>
<td>Global strain</td>
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<tr>
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<td>Circumferential (n=118), %</td>
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<td>-22±4</td>
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<tr>
<td>Radial (n=64), %</td>
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<td>51±11</td>
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<td>Radial (n=64), %</td>
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<tr>
<td>Middle strain</td>
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<td>Radial (n=64), %</td>
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</tr>
<tr>
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<tr>
<td>Radial (n=64), %</td>
<td>43±11</td>
<td>51±13</td>
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</table>

(Continued)

Table 1. Continued

<table>
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</tbody>
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Interobserver variability for echocardiographic measurements was obtained by the analysis of measurements in 10 randomly selected patients by 2 independent blinded observers. Intraobserver variability was performed by the analysis of measurements in the other 10 patients by the same observer at 2 different time points. The results were analyzed by both least squares fit linear regression analysis and the Bland–Altman method.

Results

Clinical Characteristics

The patients’ clinical and echocardiographic characteristics are summarized in Table 1. Patients with MVP showed increased MV annular area, MR severity, and LV volumes compared with controls (P<0.001). Cross-sectional area was significantly increased in all apical, middle, and basal LV (P<0.05). B/M-A LV cross-sectional area ratio was greater in patients with MVP (P<0.001), demonstrating the basal predominance of LV dilatation in this group. There were no significant differences in LV ejection fraction and global strain between the 2 groups. Basal LV strain was significantly reduced in patients with MVP compared with that in controls (P<0.001), whereas middle and apical LV strains were similar between the 2 groups. Consequently, a significantly lower B/M-A LV strain ratio was observed in patients with MVP (P<0.001), demonstrating the basal predominance of reduced LV contraction in this group.

Characteristics of the Basal Predominance of LV Dilatation and Reduced Contraction

The B/M-A LV cross-sectional area ratio was correlated with MV annular area (r=0.58, P<0.001; Figure 3A). Multivariable analysis further identified that B/M-A LV cross-sectional area ratio was independently associated with MV annular area (β=0.60, P<0.001), but not with MR volume (Table 2).

The B/M-A LV longitudinal strain ratio correlated with B/M-A LV cross-sectional area ratio (r=−0.48) and MV annular area (r=−0.48; both P<0.001; Figure 3B and 3C).
In multivariable analysis, reduced B/M·A LV strain ratio was independently associated with B/M·A LV cross-sectional area ratio ($\beta=-0.32, P<0.001$) and with MV annular dilatation ($\beta=-0.22, P=0.02$), but showed no association with LV ejection fraction or MR volume ($P=0.1$; Table 2). Circumferential and radial strain also showed the basal predominance of reduced LV contraction (Table 1; Table I in the Data Supplement), which showed similar trend of association with MV annular area ($\beta=-0.32$ and $-0.38, P<0.01$, respectively) and B/M·A LV area ratio ($\beta=-0.05$ and $-0.46, P=0.6$ and $<0.001$, respectively).

Intervendor difference between QLAB and EchoPac showed not extreme but significant differences in longitudinal and circumferential strain value (Table I in the Data Supplement), as previously reported. Intervendor difference between QLAB and EchoPac showed not extreme but significant differences in longitudinal and circumferential strain value (Table I in the Data Supplement), as previously reported. Both vendors demonstrated the basal predominance of reduced LV contraction. MV annular dilatation was associated with the basal predominance of LV dilatation ($\beta=0.60$ and $0.49, P<0.01$, respectively), which was further associated with reduced basal LV contraction (longitudinal strain; $\beta=-0.29$ and $-0.37, P<0.01$ for QLAB and EchoPac, respectively) in both vendors.

In 104 patients with single segment MVP, there was no significant difference in basal LV posterior wall longitudinal strain between patients with P2 prolapse and those without it ($-18\pm5\%$ versus $-20\pm5\%, P=0.06$). In 44 patients with P2 prolapse, basal LV posterior wall longitudinal strain was not different compared with averaged other basal LV wall strain ($-18\pm5\%$ versus $-17\pm3\%, P=0.3$). Further lesion-specific analyses for P3 and A2 prolapse showed similar results in inferior and septal walls (Figure I in the Data Supplement). In addition, in 11 patients with global MVP, there was no difference in longitudinal strain between basal anteroseptal wall without direct MV leaflet attachment and other basal walls with MV leaflet attachment ($-16\pm7\%$ versus $-20\pm3\%, P=0.2$). These suggest that local influences from segmental MVP on its adjacent LV wall contraction may not be significant.

### Changes in LV Geometry and Contraction After Surgical MV Plasty
Surgical MV plasty was performed in 35 patients due to heart failure (n=24), palpitation by atrial fibrillation (n=5), pulmonary hypertension (n=4), or reduced LV ejection fraction (n=2). Surgical MV plasty with ring implantation included artificial chordal reconstruction in 25, leaflet resection in 20, and edge-to-edge repair in 2, and patch augmentation in 1 patient. Ring size was determined by intertrigone distance (just size) and was $32\pm3$ mm. Concomitant procedures were tricuspid valve surgery in 14, Maze procedure in 6, pulmonary vein isolation in 2, and left atrium appendage closure in 5 patients. Pre- and postoperative echocardiographic measurements were done using a same vendor system for each patient to minimize the problems of intervendor reproducibility, and results are summarized in Table 3. MR volume and MV annular area significantly decreased after surgery.

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<th>Variables</th>
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<th>Multivariable</th>
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<tr>
<td>LV end-systolic volume</td>
<td>0.28</td>
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<td>MR volume</td>
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<td>MV annular area</td>
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<td>Strain ratio</td>
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<tr>
<td>Area ratio</td>
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</tbody>
</table>

LV indicates left ventricle; MR, mitral regurgitation; and MV, mitral valve.
A Representative Patient

This patient had global MVP, prominent MV annular dilatation (large yellow arrows), predominantly basal LV dilatation (large white arrows), and reduced basal LV contraction (pink signals on color strain imaging; Figure 5A; Movie I, left, in the Data Supplement). Figure 5B shows the bull’s eye image of the reduced basal LV strain (pink signals in the entire LV base). After MV plasty with annular size reduction (small yellow arrows), predominantly basal LV dilatation and reduced contraction clearly altered (small white arrows and yellow arrows), predominantly basal LV dilatation and reduced contraction clearly altered (small white arrows and yellow stars in Figure 5C and 5D, and Movie I, right, in the Data Supplement). Movies II to V in the Data Supplement show consistent images in LV short-axis circumferential and radial strain.

Measurement Variability

Good correlations were observed in inter- and intraobserver variability of echocardiographic measurements. Values were $r=0.90$ and 0.93 for B/M-A LV area ratio, $r=0.89$ and 0.95 for B/M-A LV strain ratio, and $r=0.98$ and 0.95 for MV annular area, respectively. From the Bland–Altman method, inter- and intraobserver variabilities were 4.3% and 3.6% for B/M-A LV area ratio, 5.0% and 4.3% for B/M-A LV strain ratio, and 3.0% and 4.2% for MV annular area.

Discussion

This study demonstrated that basal LV contraction was regionally and significantly reduced in patients with MVP. The basal predominance of LV dilatation was also significant in these patients. These basal LV abnormalities were proportional to MV annular dilatation. The study results seem consistent with hypothesis no. 1 of this study.

The indices of LV contraction such as ejection fraction or global LV longitudinal strain significantly reduced after surgical MV plasty. This finding is consistent with previous study.12 We do not consider that the postoperative reduction in LV ejection fraction and others express LV dysfunction caused by surgery. Preoperative ejection fraction or strain can be overestimated because of the presence of MR, and this overestimation disappears after surgery. In fact, LV maximal elasticity increases, but LV ejection fraction decreases after MV surgery for MR.13 Therefore, the postoperative reduction in LV ejection fraction or strain in this study does not necessarily indicate postoperative LV dysfunction. Because postoperative disappearance of the overestimated LV contraction may influence the whole LV, the postoperative increase in B/M-A LV strain ratio in this study seems to indicate the alteration of basal predominance of reduced LV contraction. The basal predominance of LV dilatation also altered after surgery. The alteration in basal LV abnormality was proportional to the reduction in MV annular area ($r=-0.53$, $P=0.01$; Figure 4), but was not proportional to the reduction in MR severity ($r=0.23$, $P=0.2$). This postoperative alteration further supports this study’s hypothesis. In patients with MVP, therefore, MV annular dilatation is related to the basal predominance of LV dilatation and reduced contraction, which can be altered by surgical MV plasty with annular size reduction.

A potential mechanism for these findings can be suggested by stress–strain relation.14 Regional dilatation of LV base can cause increased wall tension of the region by Laplace’s law, which will act as afterload to the region.
This can result in regionally augmented afterload and reduced contraction in the LV base. Alteration of the basal predominance of reduced LV contraction after MV surgery can also be explained by the reduction of regionally augmented afterload on the basal LV myocardium. Another mechanism can be the tension from the systolic MV leaflet. Systolic MV, especially when it is large and prolapsed, may stretch adjacent basal LV wall and cause reduction in its contraction.

Interpretation of the postoperative alteration of the basal predominance of reduced LV contraction requires careful consideration. Postoperatively increased B/M·A LV strain ratio may suggest improved basal LV contraction because of the reduction in regionally augmented tension. However,
basal LV strain value itself worsened postoperatively. Because it is not simple to evaluate myocardial contractility from strain, especially in the presence of MR, improvement in the basal LV contractility after surgery was not established in this study. Careful interpretation and further investigations are required for the altered basal predominance of reduced LV contraction after surgery.

**Correlation With Previous Investigations**

In addition to MVP per se, reduction in basal LV contraction has been reported by angiographic studies.1 This study confirmed these studies with echocardiographic images, and further demonstrated a significant correlation between reduced basal LV contraction and basal LV and MV annular dilatation. Basal predominance of LV reduced contraction altered after surgical MV plasty with basal LV and MV annular size reduction, which further supports the correlation, has not been previously reported. Significant effects of MV annular size reduction for basal LV geometry or contraction have been reported in animal models with global LV dysfunction.19 The study’s findings are consistent with these reports, and further demonstrate significant effects of MV annular size reduction on basal LV geometry and contraction in patients with MVP.

Multiple studies have reported the importance of LV and MV interactions. LV abnormalities can cause MV dysfunction. Typical case is ischemic MR where LV dilatation with displaced papillary muscles tethers MV leaflets and causes MR,16 MV abnormalities can also cause LV dysfunction. Typically, primary MR can cause LV dilatation/dysfunction.17 These mutual LV and MV interactions can result in a vicious cycle. Primary LV dilatation causes secondary MR, which further exaggerates LV dilatation.18 Primary MR causes secondary LV dilatation, which further promotes MR by secondary MV tethering.19 This study demonstrated a novel LV and MV interaction in which MV annular dilatation can be associated with basal LV dilatation and reduced contraction. In addition to the potential role of MV annular dilatation to exacerbate MR,20 this study further demonstrated its role to dilate LV base and reduce its contraction.

**Clinical Implications**

MV annular dilatation in patients with MVP was associated with the basal predominance of reduced LV contraction and dilatation, which was subsequently altered after MV plasty with ring implantation. Morrel et al21 have reported that MV repair with ring annuloplasty reduces basal LV myocardial stress. This supports the concept that before repair, there are increased stress in the LV base. Results of this study are consistent with this report. It may be important to recognize that surgical MV plasty with annular size reduction potentially have significant effects for eliminating MR and altering basal LV myocardial geometry and contraction,21 especially in patients with a large MV annulus. When MR is eliminated by surgical MV leaflet repair, it is controversial whether ring implantation is still necessary.22 This study may provide an insight for ring implantation even after the elimination of MR with surgical leaflet repair. In addition, MRI study has demonstrated frequent myocardial fibrosis in the LV base in patients with MVP.23 Ventricular arrhythmia is critically important in patients with MVP,24 and its origin is frequent in the LV base.25 Results of this study may suggest potential relationship between MV annular dilatation and basal LV fibrosis or arrhythmia, which may promote further studies and offer considerations in clinical management. Therefore, potential and incremental effects by ring implantation can be a consideration for the early surgical repair26 and for the choice of surgical MV plasty with annulus reduction or percutaneous MV leaflet tip catheter intervention without annulus reduction.27

In cases of LV segmental dysfunction, the possibility of coronary artery disease needs to be considered. The reduced basal LV contraction in this study was observed in patients with MVP, but without evidence of coronary artery disease. Typical patients with MVP and MV annular dilatation showed reduced contraction in the entire LV base (Figure 5B), which is not consistent with the coronary territory. Therefore, considering MV annulus size and regional extent of reduced LV contraction may help interpret the possible cause to avoid unnecessary examinations for coronary ischemia.

**Study Limitations**

Myocardial function can ideally be evaluated by the stress–strain relationship. However, only strain was evaluated in this study. Alteration of the basal predominance of LV reduced contraction and dilatation after MV surgery were proportional to MV annular size reduction. However, the correlation between altered basal LV contraction and implanted ring size was not clarified because all patients underwent MV surgery with just size ring. Because the standard MV surgery is accompanied with both MR elimination and annulus reduction, effects of isolated MR elimination or isolated annular size reduction were not clarified. We selected patients with MVP because maximal dilatation of the MV annulus is seen in this entity.2 Frequent surgeries with annular size reduction in MVP also offer unique opportunities to investigate the correlation between MV annular dilatation and isolated LV contraction. Whether the observed correlation between MV annular dilatation and basal LV abnormality can be extrapolated to other pathogenesis that cause MV annular dilatation, such as lone atrial fibrillation or global LV dysfunction, remains to be clarified. Whether the observed correlation can be extrapolated to tricuspid annular dilatation and right ventricular contraction also remains to be clarified.28 In this study, basal predominance of reduced LV contraction altered early after the surgery. Chronic effects after surgery remains unclarified. Finally, postoperatively, MR volume by continuity equation was negative, which demonstrates limitation of measuring regurgitant volume using this technique. We, therefore, used both continuity equation and proximal isovelocity surface area methods, and results were approximately consistent in both the methods. Nevertheless, the purpose of this study was achieved because it demonstrated that patients with MVP frequently have basal predominance of LV dilatation and reduced contraction, which is related to MV annular...
dilatation and can potentially be altered by surgical MV plasty with annular size reduction.

Acknowledgments

We thank Akiomi Inoue, PhD (Department of Mental Health, Institute of Industrial Ecological Sciences, University of Occupational and Environmental Health), and Kenji Sunagawa, MD (Center for Cardiovascular Disruptive Innovation, Kyushu University), for critical suggestions and statistical analysis.

Sources of Funding

Drs Fukuda, Mahara, Takeuchi, Eto, Nishimura, Takanashi, and Otsuji were supported by Grants-in-aid for Scientific Research (15K10226 for Drs Fukuda, Mahara, Takeuchi, Eto, Nishimura, Takanashi, and Otsuji). Dr Levine was supported by grants R01 HL109506 and HL128099 from the National Institutes of Health, Bethesda, MD.

Disclosures

None.

References


Reduced left ventricular (LV) contraction in its base has been reported in patients with mitral valve prolapse (MVP), but its mechanism was unclear. Patients with MVP frequently have prominent mitral valve (MV) annular dilatation, which suggests association of basal predominance of LV dilatation. This regional dilatation in the LV base may cause greater systolic wall tension by Laplace’s law, leading to regionally attenuated contraction in the LV base. We hypothesized that MV annular dilatation in patients with MVP can be associated with basal predominance of LV dilatation, which is associated with reduced contraction in the LV base. We further hypothesized that such basal predominance of LV abnormality may be restored by surgical MV plasty with annular size reduction. In this investigation using speckle-tracking echocardiography, patients with MVP showed basal predominance of LV dilatation (base to middle-apical cross-sectional area ratio), which was proportional to MV annular dilatation. Basal predominance of LV dilatation was further associated with basal predominance of reduced LV contraction. This basal predominance of LV dilatation and reduced contraction was restored by surgical MV plasty with annular size reduction. These suggest that patients with MVP and annular dilatation have basal predominance of LV dilatation and reduced contraction. Novel MV annular–LV interaction is suggested, and surgical MV plasty may have beneficial influences beyond the effects of eliminating MR, especially in patients with MVP and a large MV annulus.
Basal Left Ventricular Dilatation and Reduced Contraction in Patients With Mitral Valve Prolapse Can Be Secondary to Annular Dilatation: Preoperative and Postoperative Speckle-Tracking Echocardiographic Study on Left Ventricle and Mitral Valve Annulus Interaction

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_Circ Cardiovasc Imaging_. 2016;9:
doi: 10.1161/CIRCIMAGING.115.005113

_Circulation: Cardiovascular Imaging_ is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 1941-9651. Online ISSN: 1942-0080

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http://circimaging.ahajournals.org/content/9/10/e005113

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SUPPLEMENTAL MATERIAL.

Basal Left Ventricular Dilatation and Reduced Contraction in Patients with Mitral Valve Prolapse can be Secondary to Annular Dilatation: Pre- and Post-operative Speckle Tracking Echocardiographic Study on Left Ventricle and Mitral Valve Annulus Interaction

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Supplemental Table 1 and Figure 1, and Legends for Supplemental Movies 1 to 5 and Figure 1.
Supplemental Table 1. Longitudinal, circumferential and radial strain by QLAB and EchoPac.

<table>
<thead>
<tr>
<th></th>
<th>QLAB (n=96)</th>
<th>EchoPac (n=64)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MVP (n=84)</td>
<td>Controls (n=12)</td>
</tr>
<tr>
<td><strong>Longitudinal strain</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global, %</td>
<td>-20±3</td>
<td>-21±2</td>
</tr>
<tr>
<td>Apex, %</td>
<td>-20±4</td>
<td>-19±3</td>
</tr>
<tr>
<td>Middle, %</td>
<td>-21±4</td>
<td>-22±4</td>
</tr>
<tr>
<td>Base, %</td>
<td>-17±4*</td>
<td>-21±2</td>
</tr>
<tr>
<td>Basal/middle-apical ratio</td>
<td>0.83±0.15*</td>
<td>1.04±0.08</td>
</tr>
<tr>
<td><strong>Circumferential strain</strong></td>
<td></td>
<td></td>
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<tr>
<td>Global, %</td>
<td>-24±3</td>
<td>-25±3</td>
</tr>
<tr>
<td>Apex, %</td>
<td>-25±5</td>
<td>-24±4</td>
</tr>
<tr>
<td>Middle, %</td>
<td>-25±6</td>
<td>-25±4</td>
</tr>
<tr>
<td>Base, %</td>
<td>-22±4*</td>
<td>-25±4</td>
</tr>
<tr>
<td>Basal/middle-apical ratio</td>
<td>0.87±0.17*</td>
<td>1.01±0.11</td>
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<tr>
<td><strong>Radial strain</strong></td>
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<td></td>
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<tr>
<td>Global, %</td>
<td>46±10</td>
<td>51±11</td>
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<tr>
<td>Apex, %</td>
<td>47±15</td>
<td>46±15</td>
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<tr>
<td>Middle, %</td>
<td>49±17</td>
<td>55±12</td>
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<tr>
<td>Base, %</td>
<td>43±11*</td>
<td>51±13</td>
</tr>
<tr>
<td>Basal/middle-apical ratio</td>
<td>0.91±0.14*</td>
<td>1.01±0.15</td>
</tr>
</tbody>
</table>

*P<0.05 vs controls. #P<0.05 vs corresponding parameter by QLAB. MVP indicates mitral valve prolapse.
Patients with P2 prolapse

- Basal posterior wall
  - P = 0.06
  - Longitudinal strain (%): P2 prolapse (n=44) = -18 ± 5, Non-P2 prolapse (n=60) = -20 ± 5

- Basal inferior wall
  - P = 1.0
  - Longitudinal strain (%): P3 prolapse (n=29) = -18 ± 6, Non-P3 prolapse (n=75) = -18 ± 5

- Basal septal wall
  - P = 0.6
  - Longitudinal strain (%): A2 prolapse (n=15) = -17 ± 6, Non-A2 prolapse (n=89) = -18 ± 5

Patients with P3 prolapse

- Basal posterior wall
  - P = 0.3
  - Longitudinal strain (%): Posterior base = -18 ± 5, Other base = -17 ± 3

- Basal inferior wall
  - P = 0.1
  - Longitudinal strain (%): Inferior base = -18 ± 6, Other base = -16 ± 4

- Basal septal wall
  - P = 0.1
  - Longitudinal strain (%): Septal base = -17 ± 6, Other base = -20 ± 3
Legends for Supplemental Movies 1 to 5 and Figure 1.

**Movie 1:** Apical 4-chamber raw and longitudinal color strain images in a patient with mitral valve prolapse (MVP). This patient had a prominent mitral valve (MV) annular dilatation (left movie, large yellow arrows, dimension = 51 mm) and basal-predominance of left ventricular (LV) dilatation (left movie, large white arrows). Prior to MV surgery, speckle tracking analysis demonstrated reduced basal LV longitudinal contraction seen as pink signals (left movie, large white arrows). After surgical MV plasty with annular size reduction (right movie, small yellow arrows), the basal predominance of LV dilatation as well as reduced strain disappeared (right 2 movies).

**Movie 2:** Pre-operative echocardiograms of basal, middle and apical left ventricular (LV) short axis view. Color images show speckle tracking analysis of LV circumferential strain.

**Movie 3:** Post-operative echocardiograms of basal, middle and apical left ventricular (LV) short axis view. Color circumferential strain image shows improved strain in LV base compared to a pre-operative image (movie 2).

**Movie 4:** Pre-operative echocardiograms of basal, middle and apical left ventricular (LV) short axis view. Color images show speckle tracking analysis of LV radial strain.
**Movie 5:** Post-operative echocardiograms of basal, middle and apical left ventricular (LV) short axis view. Color radial strain image shows improved strain in LV base compared to a pre-operative image (movie 4).

**Figure 1:** In 104 patients with single segment mitral valve prolapse, there was no difference in the basal left ventricular (LV) posterior wall longitudinal strain between patients with and without P2 prolapse (left upper panel). Similarly, there was no difference in the corresponding basal LV longitudinal strain between patients with and without P3 prolapse (middle upper panel) as well as between patients with and without A2 prolapse (right upper panel). In addition, in 44 patients with P2 prolapse, there was no difference in the strain between basal LV posterior wall and averaged other basal LV wall (lower left panel). Similarly, there were no differences in the corresponding regional strains in 29 patients with P3 prolapse (lower middle panel) as well as in 15 patients with A2 prolapse (lower right panel).