Preservation of Mobility of the Posterior Mitral Leaflet After Mitral Valve Repair With Neochordae Using Loop Technique

Hiroto Kitahara, MD; Mitsushige Murata, MD; Kazuma Okamoto, MD; Mikihiko Kudo, MD; Akihiro Yoshitake, MD; Hikaru Tsuruta, MD; Yuji Itabashi, MD; Keiichi Fukuda, MD; Ryohei Yozu, MD; Hideyuki Shimizu, MD

Background: Recently, the loop technique has been standardized for mitral valve repair, with excellent long-term outcomes reported. This study thus analyzed whether the loop technique could preserve mitral leaflet mobility on trans-thoracic echocardiography.

Methods and Results: Among 367 concomitant patients who underwent mitral valve repair at Keio University Hospital between January 2007 and December 2014, 304 patients had a prolapse of the posterior leaflet. Of these, 84 cases assessed on echocardiography were retrospectively analyzed for this study. These patients were divided into 4 groups based on the procedure used: (1) group L1 (n=28), loop technique alone; (2) group L2 (n=14), loop technique with resection and suture; (3) group L3 (n=33), loop technique with plication of indentation; and (4) group R (n=9), resection and suture alone. The mean postoperative mobile posterior mitral leaflet (PML) angles in groups L1 and L2 (39.3±16.0°, 37.3±16.0°) were significantly larger than those in groups L3 and R (18.8±15.7°, 15.3±15.7°), respectively (P<0.01). Ring size, age, and mobile PML angle had a statistically significant correlation with the postoperative mean mitral valve pressure gradient (P<0.05).

Conclusions: The loop technique preserved PML mobility and enabled implantation of a larger ring, resulting in a reduced mean mitral valve pressure gradient. (Circ J 2016; 80: 663–667)

Key Words: Leaflet mobility; Loop technique; Mitral valve repair

mobility of the mitral valve leaflet is important for dynamic movement of the valve apparatus. A rigid leaflet following mitral valve repair could affect mitral valve hemodynamics, thus preservation of leaflet mobility is important to avoid stenosis, regurgitation, and systolic anterior motion during such procedures. Several mitral valve repair techniques have been developed and improved recently. Leaflet resection and ring annuloplasty are conventionally used, especially for prolapse of the posterior mitral leaflet (PML), and have good short- and long-term outcomes. This technique, however, may reduce leaflet mobility, affecting long-term durability. In contrast, non-resectional mitral valve repair with the loop technique using artificial chordae made of expanded polytetrafluoroethylene (ePTFE, GORE TEX; W. L. Gore and Associates, Flagstaff, AZ, USA) is now a standardized procedure associated with a high success rate, and excellent short- and long-term outcomes. This technique is also reported to be better than leaflet resection in terms of preserving leaflet mobility and restoring good coaptation. Although selection of a mitral valve repair technique that preserves leaflet mobility is crucial, no studies have analyzed the correlation between leaflet mobility and the loop technique, despite echocardiography now enabling more accurate analysis of valve morphology. In this study, we therefore compared mitral valve repair techniques on echocardiography to determine whether the loop technique could preserve PML mobility.

Methods

Subjects
The ethics committee of Keio University Hospital approved this study. Between January 2007 and December 2014, 367 concomitant patients underwent mitral valve repair at Keio University Hospital. Of these, 304 patients were treated for prolapse of the PML. In total, 84 patients who were analyzed using a commercially available Vivid 7 or Vivid E9 ultrasound...
atrial septal defect (ASD) and patent foramen ovale (PFO), aortic valve replacement (AVR), and coronary artery bypass grafting (CABG) were recorded.

Echocardiography
Two-dimensional transthoracic echocardiography (TTE) was performed using a Vivid 7 or Vivid E9 ultrasound system in all patients before and after mitral valve repair. Conventional echocardiographic data including left ventricular (LV) dimension, LV ejection fraction, left atrial diameter, grade of MR, grade of tricuspid valve regurgitation, and mean mitral valve pressure gradient (MVPG) were collected. Leaflet mobility was defined by the mobile PML angle, calculated as described previously.

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\text{Mobile PML angle} = \theta_1 - \theta_2
\]

Statistical Analysis
Patient baseline characteristics, intra- and postoperative characteristics, and echocardiographic data were compared among the groups. Continuous variables are expressed as mean±SD. Differences in the variables among groups were compared using 1-way analysis of variance or Kruskal-Wallis analysis as appropriate. Post-hoc analysis was performed using the Tukey test, and paired t-test or Wilcoxon signed-rank test was used to compare between pre- and postoperative echocardiographic findings. Categorical and sequential variables are expressed as the percentage of patients and were compared using the chi-squared test or Fisher exact test as appropriate. Simple regression analysis was used to analyze the relationship between mean MVPG and other variables. Stepwise forward selection procedure was used to develop a multiple regression model predictive of the mean MVPG. Statistically significant variables based on univariate analysis were considered for inclusion in the model. P<0.05 was considered to be statistically significant.
Loop Technique Preserves Leaflet Mobility

Results

Table 1 summarizes the patient baseline characteristics. The total patient cohort (n=84) contained 58 men, and had a mean age of 55.0±13.7 years. Group L2 comprised more male patients (100%) than the other groups (P<0.05), and group R contained more patients with preoperative arrhythmia (56%) than the other groups (P<0.05). There were no statistical differences in preoperative patient characteristics among the groups for the other variables.

Surgical Techniques

Intra- and postoperative data are listed in Table 2. The mitral valve repair success rate was 100%. The mini-thoracotomy approach was used in 73 patients (87%), none of whom underwent conversion to sternotomy. The annuloplasty ring size ranged from 26 to 38 mm, with the mean size in groups L1 and L2 (32.3±3.1 mm and 33.0±2.5 mm, respectively) significantly larger than that in group R (28.7±1.7 mm), and artificial chordal was used in 3.8±1.8 patients (excluding group R). The statistical analysis was conducted using IBM SPSS 22.00 (IBM, Chicago, IL, USA).

Table 1. Preoperative Patient Characteristics

| Variables          | Group L1 | Group L2 | Group L3 | Group R |
|--------------------|----------|----------|----------|---------|
| n                  | 28       | 14       | 33       | 9       |
| Age (years)        | 54.3±12.0| 57.8±11.5| 54.8±13.2| 57.3±19.5|
| Male               | 18 (64)  | 14 (100)*| 19 (58)  | 7 (78)  |
| Height (cm)        | 169.30±9.7| 171.4±3.3| 165.9±9.6| 165.9±7.0|
| Weight (kg)        | 61.4±8.0 | 67.8±8.1 | 60.3±9.9 | 60.5±7.1 |
| BSA (m²)           | 1.70±0.14| 1.79±0.10| 1.67±0.18| 1.67±0.13|
| eGFR (ml/min/1.73m²)| 71.9±18.2| 62.9±18.9| 69.9±14.7| 67.6±27.8|
| HTN                | 11 (39)  | 10 (71)  | 20 (61)  | 6 (67)  |
| DL                 | 5 (18)   | 3 (21)   | 9 (27)   | 2 (22)  |
| DM                 | 3 (11)   | 0 (0)    | 2 (6)    | 1 (11)  |
| COPD               | 1 (4)    | 0 (0)    | 2 (6)    | 0 (0)   |
| Smoking            | 2 (7)    | 1 (7)    | 3 (9)    | 0 (0)   |
| CHF                | 9 (33)   | 7 (50)   | 19 (61)  | 6 (67)  |
| AF/AFI             | 2 (7)    | 1 (7)    | 6 (18)   | 5 (56)* |
| CVA                | 1 (4)    | 0 (0)    | 0 (0)    | 0 (0)   |
| Previous cardiac surgery | 1 (4) | 0 | 1 (3) | 0 |

Data given as mean±SD or n (%). *P<0.05 vs. other groups. AF, atrial fibrillation; AFI, atrial flutter; BSA, body surface area; CHF, congestive heart failure; COPD, chronic obstructive pulmonary disease; CVA, cerebrovascular accident; DL, dyslipidemia; DM, diabetes mellitus; eGFR, estimated glomerular filtration rate; HTN, hypertension.

Table 2. Intra- and Postoperative Data

| Intraoperative variables | Group L1 | Group L2 | Group L3 | Group R |
|--------------------------|----------|----------|----------|---------|
| n                        | 28       | 14       | 33       | 9       |
| Operation time (min)     | 357.9±67.5| 371.8±78.6| 382.4±78.1| 365.7±100.0|
| CPB time (min)           | 245.8±58.9| 258.5±66.9| 267.6±68.1| 248.1±67.8|
| AXC time (min)           | 170.1±51.0| 171.1±38.9| 195.8±45.1| 161.4±52.1|
| BTF                      | 6 (21)   | 4 (29)   | 21 (64)**| 4 (44)  |
| Number of loops          | 4.3±1.9 | 3.1±1.3 | 3.5±1.6 | –       |
| Ring size (mm)           | 32.3±3.1**| 33.0±2.5**| 31.2±3.0 | 28.7±1.7|
| Physio ring              | 4 (24)   | 0 (0)    | 3 (10)   | 0 (0)   |
| Physio II ring           | 7 (41)   | 8 (57)   | 17 (55)  | 5 (56)  |
| CG future ring           | 3 (18)   | 0 (0)    | 6 (19)   | 2 (22)  |
| Cosgrove ring            | 2 (12)   | 5 (36)   | 3 (10)   | 1 (11)  |
| Tailor band/others       | 1 (6)    | 1 (7)    | 2 (6)    | 1 (11)  |

| Postoperative variables  | Group L1 | Group L2 | Group L3 | Group R |
|--------------------------|----------|----------|----------|---------|
| Respiratory support (days)| 0.96±0.56| 1.29±1.14| 0.94±0.25| 1.00±0.61|
| ICU stay (days)          | 1.96±0.56| 2.21±1.19| 1.94±0.35| 3.33±4.00|
| Arrhythmia               | 3 (11)   | 1 (7)    | 3 (9)    | 4 (44)* |
| Reoperation              | 0        | 0        | 0        | 0       |
| In-hospital mortality    | 0        | 0        | 0        | 0       |

Data given as mean±SD or n (%). *P<0.05 vs. the other groups, **P<0.01 vs. group R. AXC, aorta cross-clamp; BTF, blood transfusion; CPB, cardiopulmonary bypass; ICU, intensive care unit.
size of mitral annuloplasty ring was chosen based on the area of the anterior leaflet. Inter-commisural and inter-trigonal diameter were also used as references. Intraoperative blood transfusion use was significantly higher in group L3 (65%) than in the other groups, although there were no statistical differences among the groups in operative time, cardiopulmonary bypass time, aortic cross-clamp time, and type of ring used. Concomitant with mitral valve repair, tricuspid valve repair was performed in 9 patients, using a 28-mm and 30-mm Edwards MC3 Tricuspid Annuloplasty Ring (Edwards Lifesciences) in 5 and 4 patients, respectively. Ten patients with perioperative paroxysmal atrial fibrillation underwent maze procedure using Isolator Synergy Clamps (AtriCure, OH, USA), while ASD and PFO closure was performed in 4 patients, AVR in 1 patient, and CABG in 1 patient. After surgery, none of the patients needed a second surgery for residual MR, and all patients survived the hospitalization. Finally, there was no correlation between surgical techniques and postoperative complications.

### Discussion

In this study, we investigated whether the loop technique can preserve the mobility of mitral valve leaflets during surgical repair. We found that the loop technique conserves leaflet mobility more robustly than the resection technique, indicating that the loop technique may give physiologically better results in both the short and long term.

Echocardiography

No statistically significant differences existed among the groups for preoperative TTE findings, and postoperative echocardiographic data are summarized in Table 3. The severity of MR decreased significantly, from 3.7±0.5 to 1.1±0.7 postoperatively, while the mean mobile PML angles in groups L1 and L2 (39.3±16.0° and 37.3±16.0°, respectively) were significantly greater than those in groups L3 and R (18.8±15.7° and 15.3±15.7°, respectively). On simple regression analysis, ring size (R²=0.288), age (R²=0.060), and mobile PML angle (R²=0.075) had a statistically significant correlation with the postoperative mean MVPG. On multivariate regression analysis, annuloplasty ring size, age, and mobile PML angle all independently predicted MVPG, with larger ring size (non-standardized coefficient=–0.216), older age (non-standardized coefficient=–0.023), and larger mobile PML angle (non-standardized coefficient=–0.012) as significant predictors of smaller mean MVPG (Table 4).

### Table 3. Postoperative Echocardiography

| Variables      | Group L1 | Group L2 | Group L3 | Group R |
|----------------|----------|----------|----------|---------|
| LVEDD (mm)     | 48.1±5.3 | 47.6±3.4 | 46.0±6.7 | 49.7±6.1 |
| LVESD (mm)     | 32.0±4.5 | 31.8±3.1 | 30.5±5.9 | 34.0±7.6 |
| LVEF (%)       | 69.0±8.9 | 69.7±5.4 | 66.9±8.9 | 63.5±10.1|
| LAD (mm)       | 35.8±8.4 | 37.4±6.5 | 35.5±6.7 | 39.8±13.6|
| MR             | 1.3±0.7  | 1.1±0.8  | 1.0±0.7  | 1.2±0.4  |
| TR             | 1.3±0.6  | 1.4±0.5  | 1.3±0.6  | 1.3±0.5  |
| Mobile PML angle (°) | 39.3±16.0** | 37.3±16.0** | 18.8±15.7 | 15.3±15.7 |
| Mean MVPG (mmHg) | 2.4±1.3  | 2.4±1.0  | 2.9±1.3  | 3.4±1.4  |

Data given as mean ± SD. **P<0.01 vs. group R. LAD, left atrial diameter; LVEDD, left ventricular end diastolic diameter; LVESD, left ventricular end systolic diameter; LVEF, left ventricular ejection fraction; MR, mitral regurgitation; MVPG, mitral valve pressure gradient; PML, posterior mitral leaflet; TR, tricuspid regurgitation.

### Table 4. Significant Predictors of MVPG

| Variables      | Univariate | Multivariate |
|----------------|------------|--------------|
|                | R²         | P-value      | Non-standardized coefficient | P-value |
| Ring size      | 0.288      | <0.001       | –0.216                       | <0.001  |
| Age            | 0.060      | 0.025        | –0.023                       | 0.006   |
| Mobile PML angle | 0.075     | 0.012        | –0.012                       | 0.041   |
| Height         | 0.030      | 0.112        |                             |         |
| Weight         | 0.000      | 0.909        |                             |         |
| BSA            | 0.003      | 0.596        |                             |         |
| LVEDD          | 0.041      | 0.067        |                             |         |
| LVESD          | 0.012      | 0.328        |                             |         |
| Number of loops| 0.004      | 0.562        |                             |         |
| Postoperative MR | 0.001    | 0.774        |                             |         |

Abbreviations as in Tables 1, 3.
surgery, and ease in removal and repositioning. We subsequently established a modified loop-in-loop technique, which makes it easier to adjust the length of neochorda and enables the repair of several leaflet lesions.8,11 In the present study, 73 of the patients (87%) underwent mini-thoracotomy with a 100% success rate. The patients in group L3 needed more blood transfusions than those in the other group because of the higher number of leaflet lesions, but there was no difference among the groups in mean operative time or cardiopulmonary bypass time, nor in the incidence of postoperative complications. This suggests that the loop technique is similar to other options in eliminating MR within the same time limit (preoperative to postoperative MR, 3.7±0.5 to 1.0±0.7). In addition, the loop technique had the added advantages of better preservation of leaflet mobility and appropriate ring placement. It is now well accepted that effective mitral valve repair diminishes MR, and many surgeons are now addressing the next step of better long-term prevention of functional mitral stenosis after mitral valve repair. To prevent mitral stenosis, it is crucial to both preserve leaflet mobility and insert a physiologically suitable annuloplasty ring with respect to size. In studying these factors, Shudo et al reported that PML mobility was better preserved after non-resectional leaflet repair in which the prolapsed leaflet tissue is inverted into the left ventricle, compared with the quadrangular resection technique,12 while Ben Zekry et al found that a non-resectional mitral valve repair technique preserved motion of the posterior leaflet and dynamic changes in the mitral annulus compared with resectional valve repair.5 The latter authors also emphasized the importance of leaflet mobility, especially in the PML, for preserving normal stress distribution throughout the valve. Leaflet resection can result in asymmetric leaflet mobility, which could in turn influence zone of apposition and stress distribution. As shown herein for the group L2 patients, the loop technique can restore PML motion, even when resection is used. This might be because the artificial chordae enabled the partly resected leaflet to move and maintain the anatomical and dynamic relationships of the mitral valve apparatus.13 In contrast, the additional leaflet plication of indentation to the loop technique led to restriction of the leaflet mobility, as shown in group L3.

Furthermore, folding technique is also applicable to reduce the redundant leaflets. This technique is similar to that previously reported by Tsukui et al,16 and although these authors reported good short-term outcomes with this technique, further studies are needed to assess the effects of folding mitral valve repair. We now perform mitral valve repair using mainly the loop technique, and other techniques, as needed (resection and suture, plication, folding) would be added to obtain long-term durability. Ring selection should be based on the area of anterior leaflet, and therefore the mean size of the ring should not be smaller in the resection and suture patients (group R). We tended to choose smaller rings in the resection and suture patients, however, compared with those undergoing non-resection techniques, due to the phycological misconception that a smaller ring could create a larger coaptation area. In contrast, in the non-resection groups, the preserved redundant posterior leaflet led surgeons to choose a larger ring size. Preservation of the redundant posterior leaflet is also related to the occurrence of systolic anterior motion of the anterior mitral leaflet. To avoid this systolic anterior motion of the anterior mitral leaflet, larger ring size tended to be selected.

Study Limitations
The limitation of the present study lies in its retrospective nature. Further controlled randomized studies are needed to prove the superiority of the loop technique over other techniques. Specifically, the area of the resected leaflet might have affected the ring size or postoperative MVPG, although we did not measure that factor quantitatively during surgery in this study.

Conclusions
Mitral valve repair techniques, either non-resection or resection, can eliminate MR. The loop technique successfully preserved PML mobility and was associated with implantation of a larger annuloplasty ring, compared with the triangular resection technique. This would result in a reduced mean MVPG, and potentially the prevention of mitral stenosis in the long term after surgery. The loop technique could therefore be hemodynamically superior and easier to perform in complex cases especially in minimally invasive cardiac surgery.

Conflict of Interest
None declared.

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