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Papillary Muscle Relocation in Secondary Mitral Regurgitation: Midterm Outcomes

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Abstract

Background: Mitral valve repair in secondary mitral regurgitation is still uncertain as the chance of recurrence is approximately 30 percent after solely undersized annuloplasty. Some procedures adding to the subvalvular level are proposed to alleviate the recurrent rate. This study was to evaluate the clinical and echocardiographic outcomes of papillary muscle relocation plus undersized ring in secondary mitral regurgitation (2^{nd} MR). ***Methods***: Medical records of moderate to severe 2^{nd} MR with tethering depth of more than 1 cm patients who underwent papillary muscle relocation plus undersized ring from 2014 to 2020 were reviewed. Clinical and echocardiographic parameters before and after operation were analyzed. ***Results***: Thirty-two patients were included during the 6-year period. There was no perioperative mortality. Two patients died at one year from ischemic stroke and car accidents with overall 5-year survival of 93.7%. All patients were in NYHA class I and II with MR grading as trivial or mild at a median follow-up of 33 months. Postoperative mean tenting depth, area and posterior leaflet angle decreased remarkably from 1.18 cm, 2.61 cm^2 and 46.5 degree to 0.65 cm, 1.22 cm^2 and 28.6 degree, respectively ($p < 0.001$, 0.02, and 0.01). Moreover, left ventricular function and remodeling were also notably improved (EF; 38.2% vs 49.1%: $p = 0.018$, LVEDD; 62.8 vs 54.6 mm: $p = 0.005$, LVESD; 50.2 vs 42.4 mm: $p = 0.01$). ***Conclusions***: Papillary muscle relocation combined with undersized annuloplasty improved mid-term clinical outcomes. Apart from reduction of recurrent MR rate, restoration of mitral configuration and reverse LV remodeling could be the effect of adding subvalvular correction in this pathology.

Keywords

Papillary Muscle Relocation, Secondary Mitral Regurgitation, Left Ventricular, Remodeling, Tenting Depth, Tenting Area, Posterior Leaflet Angle

1. Introduction

Secondary mitral regurgitation (2^{nd} MR) or functional mitral regurgitation is the insufficiency of the mitral valve caused by the left ventricle. A consequence of myocardial infarction or primary dilated cardiomyopathy leads to left ventricular (LV) wall motion abnormalities, papillary muscle displacement, mitral annular dilatation, and eventually causes restricted leaflet movement during systole. This type of abnormal coaptation was classified as type IIIb according to Carpentier's classification [1] [2].

The occurrence of 2^{nd} MR was approximately 20% to 50% following a myocardial infarction according to previous studies [3] [4]. Although most of the cases were of a mild degree, approximately 10% of the patients had either a moderate or severe degree which was associated with future cardiac events and mortality [5].

To date, the surgical treatment of this pathology is still uncertain as the solely undersized ring annuloplasty which was previously recognized as a standard treatment demonstrates a high recurrent rate of 30% or more [6] [7]. According to the latest AHA guideline in 2017, chordal sparing valve replacement was a preferred method over downsized annuloplasty repair [8]. Another promising strategy of adjunctive subvalvular procedures to the ring annuloplasty had been reported to lower MR recurrence compared with the previous standard treatment [9]. Papillary muscle relocation is one of the subvalvular techniques which can maintain mitral geometry by pulling the papillary muscle up to reduce the downward tension on mitral leaflets from left ventricular dilatation. The present study reported the mid-term clinical and echocardiographic outcomes of papillary muscle relocation plus undersized mitral annuloplasty ring in 2^{nd} MR.

2. Patients and Methods

This study was approved by the CCIT Ethics Committee. Patients with moderate to severe 2^{nd} MR with tethering depth > 1 cm who underwent posterior papillary muscle relocation plus undersized ring annuloplasty were retrieved from patient records in the Central Chest Institute of Thailand between January 2014 and June 2020. The medical records were reviewed for patient demographics, past medical history, operative procedure, preoperative and postoperative echocardiography, morbidity, mortality, and survival. Follow-up data were collected from outpatient visits and telephone calls. Patients with structural mitral valve lesions including degenerative, rheumatic, and infective endocarditis or some conditions with concurrent aortic valve procedure or thin wall infarction scar with paradoxical movement needed accompanying left ventricular restoration surgery were excluded.

2.1. Echocardiographic Measurement

A transthoracic echocardiogram (TTE) was performed before the operation, approximately six months and annually after the operation. An intraoperative transesophageal echocardiogram was routinely performed to assess pre-operative pathology and quality after correction. Moderate and severe 2nd MR was defined as an effective regurgitation orifice area (EROA) of more than 0.2 and 0.4 cm^2, respectively. However, the MR severity assessment with additional methods including vena contracta and the jet area to the left atrial area ratio was also determined.

Left ventricular parameters such as left ventricular end-diastolic diameter (LVEDD), left ventricular end-systolic diameter (LVESD), left ventricular end-diastolic volume index (LVEDVI), left ventricular end-systolic volume index (LVESVI) and ejection fraction (EF) were measured using M mode parasternal long axis view and modified Simpson's method.

Mitral valve configurations include tenting depth—defined as the distance between the mitral annular plane and the coaptation point of the mitral valve leaflet, tenting area—defined as the area between mitral annulus plane, and both mitral leaflets in parasternal long axis view during mid systolic closure were evaluated. Furthermore, the angle between the annular plane and a line jointed the coaptation point to the posterior annulus in parasternal long axis view during mid systole called posterior leaflet angle (PLA) was also measured.

2.2. Surgical Techniques

Ascending, bicaval cannulation and myocardial protection with intermittent combined antegrade and retrograde cold blood cardioplegia techniques were used for cardiopulmonary bypass. Distal anastomosis of coronary bypass graft was done first using saphenous veins to graft non-left anterior descending (LAD) target vessels, while the left internal mammary artery (LIMA) was anastomosed to the target LAD. The proximal anastomosis was performed at the end with the side clamp technique. The mitral valve was exposed through a superior transseptal incision. Annular stitches were placed with 2-0 braided simple horizontal suture to increase exposure. Two figures of eight polytetrafluoroethylenes (CV-4, W.L. Gore, & Associates, Flagstaff, AZ) sutures were placed at the fibrous tip of the posterior papillary muscle and the free ends of each pair were passed through the posterior annulus and the rigid annuloplasty ring corresponding site of the papillary muscle. In case of severe LV dilatation with symmetrical MR jet observed from preoperative TTE, another figure of eight stitches was added to the anterior papillary muscle and repositioned to the posterior annulus in the same fashion. The saddle-shaped annuloplasty ring (Medtronic Profile 3D Annuloplasty System, Minneapolis, MN, USA) was chosen and downsized by one ring number after measuring the height of the anterior mitral leaflet. After tying down the ring and filling up the left ventricle with saline under pressure, the CV-4 suture was gradually pulled up to the point that the coaptation slightly moved upward approximately 1 mm to the annular plane with eyeball estimation.

2.3. Statistical Analysis

Results were expressed as mean ± SD. The pair t test was used for the continuous variable data set. Long-term cumulative survival was assessed with Kaplan- Meier. The analysis was performed using SPSS version 22.0 software (SPSS, Inc., Chicago, IL, USA). A p-value less than 0.05 was statistically significant.

3. Results

Thirty-two moderate to severe secondary MR patients were treated with papillary muscle relocation plus undersized rigid ring annuloplasty during the past 6 years. Of these, 56% were male with a mean age of 66 years. Seventy-four-point five percent of the patients were in New York Heart Association (NYHA) class III and IV. Approximately 80% got loop diuretics around 72% to 80% received anti aldosterone antagonists, beta-blockers and angiotensin-converting enzyme inhibitors or angiotensin II receptor blockers. A preoperative intra-aortic balloon pump (IABP) was used in one patient owing to unstable angina. Ischemia in origin was found at approximately 84.4%, whereas MR severity grading as moderate and severe were 9.4% and 91.6%. The mean EF, LVEDD, LVESD, LVEDVI, and LVESVI were 38%, 62.8 mm, 50.2 mm, 117.2 ml/m^2 and 68.6 ml/m^2, respectively (**Table 1**).

Relocation of both papillary muscles was performed in 5 patients (15.6%) who had symmetrical MR jet, while only posterior papillary muscle relocation was chosen in 27 patients (84.4%) with asymmetrical jet. The mitral annuloplasty ring size varied from 24 mm (9.4%), 26 mm (34.4%), 28 mm (31.3%) and 30 mm (25%). Concomitant procedures included coronary bypass graft in 27 patients (84.4%) with a mean number of 3.07 grafts per patient and tricuspid valve annuloplasty with a 3-dimensional ring (Contour 3D, Medtronic, Minneapolis, MN, USA) in 8 patients (25%). Mean cardiopulmonary bypass and aortic cross clamp time were 125 ± 36.3 and 90.2 ± 37.8 minutes, respectively (**Table 2**).

There was no in-hospital and 30-day mortality in the present study. IABP was used in 2 cases during the postoperative period from low cardiac output state in one case and continuation from preoperative insertion in the other. However, both patients could be weaned from the IABP within 48 hours after surgery. Mean ICU and hospital stays were 2.5 and 12.3 days, respectively. Two patients died of intracerebral hemorrhage and a car accident 12 months after the operation (**Table 3**). The survival was 93.7% at 5 years (**Figure 1**). All patients were in NYHA class I and II and recurrent MR severity was less than moderate at the median follow-up of 33 months (**Figure 2** and **Figure 3**).

Significant improvement in LV function and LV dimension parameters were observed at the follow-up period including EF (49.1% vs 38.2%; $p = 0.018$), LVEDD (54.6 vs 62.8 mm; $p = 0.005$), LVESD (42.4 vs 50.2 mm; $p = 0.01$), LVEDVI (90.5 vs 117.2 ml/m^2; $p = 0.03$) except LVESVI which improved marginally (52.5 vs 68.6 ml/m^2; $p = 0.06$). Furthermore, tenting depth, tenting area and PLA were also found to decrease significantly from 1.18 ± 0.06 cm to 0.65 ± 0.22 cm; $p < 0.001$, 2.61 ± 0.58 cm^2 to 1.22 ± 0.19 cm^2; $p = 0.02$ and 46.5 ± 6.2 degree to 28.6 ± 6.2 degree; $p = 0.01$ (**Table 4**).

Table 1. Baseline characteristics (n = 32).

Age	66.2 ± 3.4
Sex (male/female)	18/14
Comorbidity	
Diabeticmellitus	20 (62.5%)
Hypertension	22 (68.8%)
Dyslipidemia	18 (56.3%)
COPD	5 (15.6%)
Hx of stroke	2 (6.3%)
Cr level > 1.5	4 (12.5%)
Atrial fibrillation	8 (25%)
STS score	3.2 ± 0.21
NYHA Class	
II	8 (25%)
III	17 (53.1%)
IV	7 (21.4%)
Preoperative IABP	1 (3.1%)
Preoperative medication	
Loop diuretic	25 (78.1%)
Anti-aldosterone	23 (71.9%)
Beta block	24 (75%)
ACEi or ARB	26 (81.3%)
Etiology of MR	
Ischemic	27 (84.4%)
Nonischemic	5 (15.6%)
Echocardiogram	
MR grade	
moderate (ERO 0.2 - 0.4 cm^2)	3 (9.4%)
severe (ERO > 0.4 cm^2)	29 (91.6%)
EF	38.2 ± 10.8
LVEDD (mm)	62.8 ± 5.3
LVESD (mm)	50.2 ± 6.3
LVEDVi (ml/m^2)	117.2 ± 18.9
LVESVi (ml/mm^2)	68.6 ± 24.3
Tenting depth (cm)	1.18 ± 0.06
Tenting area (cm^2)	2.61 ± 0.58
TRPG (mmHg)	32.9 ± 9.5
TR grade	
severe	7 (21.8%)
moderate	1 (3.1%)

COPD = Chronic Obstructive Pulmonary Disease, STS score = Society of Thoracic Surgeon score, IABP = Intraaortic Balloon Pump, ACEi = Angiotensin Converting Enzyme Inhibitor, ARB = Angiotensin Receptor Blocker, MR = Mitral Regurgitation, ERO = Effective Regurgitant Orifice Area, EF = Ejection Fraction, LVEDD = Left Ventricular End-diastolic Diameter, LVESD = Left Ventricular End-systolic Diameter, LVEDVi = Left Ventricular End-diastolic Volume Index, LVESVi = Left Ventricular End-systolic Volume Index, TRPG = Tricuspid Regurgitation Pressure Gradient, TR = Tricuspid Regurgitation.

Table 2. Operative procedure.

Relocation procedure	
both papillary muscle	5 (15.6%)
only posterior papillary muscle	27 (84.4%)
Mitral annuloplasty	
size 24	3 (9.4%)
26	11 (34.4%)
28	10 (31.3%)
30	8 (25%)
Concomitant procedure	
CABG	27 (84.4%)
number of graft (mean)	3.07 ± 0.2
Tricuspid valve annuloplasty	8 (25%)
MAZE	1 (3.1%)
CPB time (min)	125.1 ± 36.3
Cross clamp time (min)	90.2 ± 37.8
Blood loss (ml)	750.2 ± 96.8

CABG = coronary artery bypass graft, CPB = cardiopulmonary bypass.

Table 3. Outcomes.

Early outcomes	
hospital mortality	0
bleeding with resternotomy	1 (3.1%)
IABP	2 (6.3%)
renal failure (dialysis)	0
extubating time > 24 hr	3 (9.3%)
ICU stay (day)	2.5 ± 1.5
hospital stay (day)	12.3 ± 1.4
Follow up outcomes	
late mortality	1 (3.1%)
NYHA class > 2	0
heart failure hospitalization	2 (6.3%)
recurrent MR > gr 2	0

IABP = intraaortic balloon pump, NYHA = New York Heart Association, MR = mitral regurgitation.

Table 4. Echocardiographic data.

	preop	follow up	p value
LVEF	38.2 ± 10.8	49.1 ± 14.6	0.018
LVEDD (mm)	62.8 ± 5.3	54.6 ± 8.5	0.005
LVESD (mm)	50.2 ± 6.3	42.4 ± 10.5	0.011
LVEDVi (ml/m^2)	117.2 ± 18.9	90.5 ± 27.3	0.029
LVESVi (ml/m^2)	68.6 ± 24.3	52.5 ± 25.3	0.06
tenting depth (mm)	1.18 ± 0.06	0.65 ± 0.22	<0.001
tenting area (cm^2)	2.61 ± 0.58	1.22 ± 0.19	0.02
posterior leaflet angle (degree)	46.5 ± 6.2	28.6 ± 6.2	0.01
MVA (cm^2)		2.25 ± 0.37	
MV gradient (mmHg)		3.42 ± 1.63	

EF = Ejection Fraction, LVEDD = Left Ventricular End-diastolic Diameter, LVESD = Left Ventricular End-systolic Diameter, LVEDVi = Left Ventricular End-diastolic Volume Index, LVESVi = Left Ventricular End-systolic Volume Index, MVA = Mitral Valve Area, MV Gradient = Mitral Valve Gradient.

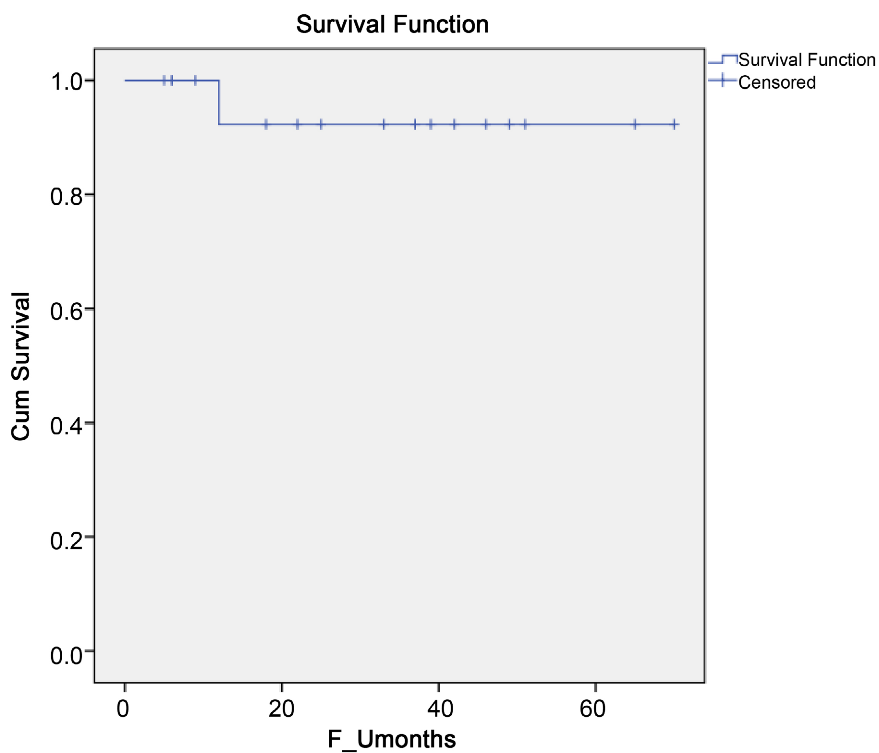

Figure 1. Survival curve.

4. Discussion

The results of this small study showed that combined papillary muscle relocation and restrictive annuloplasty demonstrated good mid-term outcomes including survival and functional class. The occurrence of recurrent MR and mitral deformity

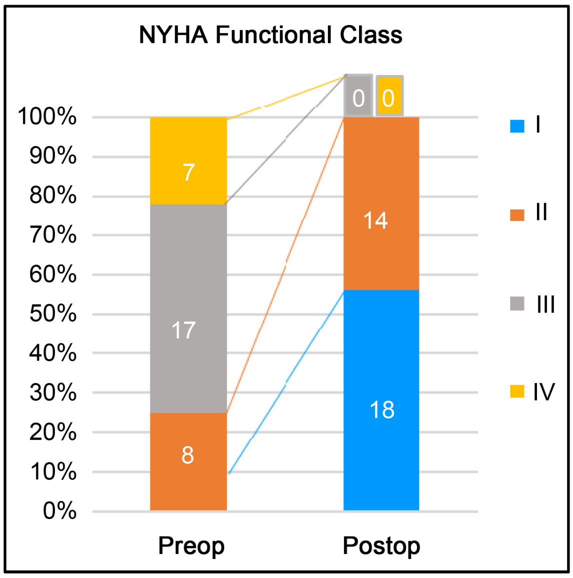

Figure 2. NYHA functional class.

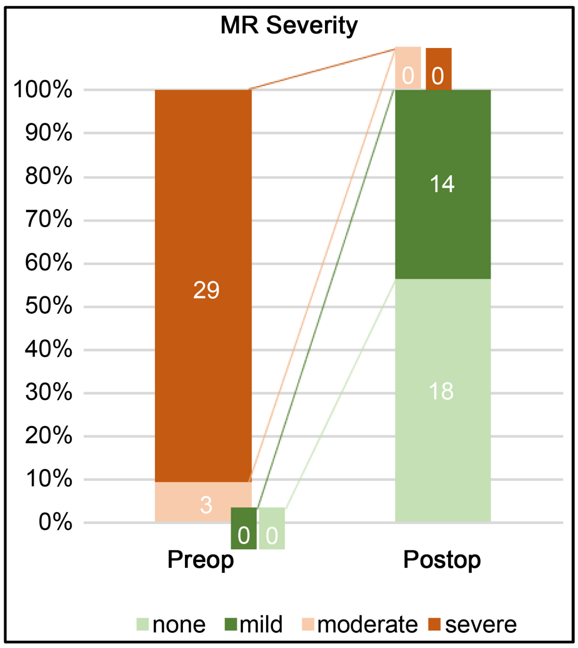

Figure 3. MR severity.

parameters such as tenting depth, tenting area and PLA were ameliorated significantly and maintained during the follow-up period.

Chronic secondary MR is a consequence of LV dysfunction and dilatation causing the displacement of papillary muscles, particularly the posterior one. As a result, the closing and tethering force on the mitral valve during the systolic phase is not balanced leading to insufficiency of the mitral valve according to type IIIbCarpentier's classification [1] [2]. From the previous studies, survival, clinical functional class, and heart failure hospitalization were impacted by the degree of the mitral insufficiency in these patients [5].

Undersized ring annuloplasty proposed by Bolling in 1998 was considered as a default strategy for the treatment of this pathology [10]. However, the recurrent rate of mitral insufficiency had been reported to vary from 5% to 60% [7] [8]. A multicenter RCT trial in 2014 demonstrated that mitral valve repair with an undersized ring not only had no clinical benefit over replacement but also had a higher recurrent regurgitation rate [11]. From the latest 2017 AHA/ACC guideline for the management of patients with valvular heart disease, mitral valve replacement with chordal sparing was in class IIa recommendation over the repair with downsized annuloplasty ring [9]. However, the latest ESC/EACT guidelines for valvular heart disease in the same year stated that mitral valve repair with an undersized complete ring was still the preferred method if there were no echocardiographic risk factors for recurrent MR such as severe mitral deformity (tenting depth >1 cm, tenting area > 2.5 cm^2, posterior leaflet angle > 45 degree) [12].

To decrease the recurrent MR rate, some maneuvers on the valvular and subvalvular levels were added to the ring annuloplasty, which showed satisfactory outcomes compared with annuloplasty alone in a recent meta-analysis [6]. However, there was no conclusive evidence on the best strategy at present time. Papillary muscle relocation was one of the techniques performed on the subvalvular level introduced by Kron in 2002 [13]. This technique could reduce the tethering force on the leaflet and stabilize long-term mitral valve function. Some reports of these combination procedures demonstrated good short and mid-term outcomes with lower recurrent MR rate and better reversed LV remodeling in both ischemic and nonischemic mitral regurgitation [14] [15].

The author believed that this technique is simple and reproducible by just putting Gortex stitches on the papillary muscle heads as we routinely performed in degenerative mitral repair then suturing them to the posterior mitral annulus and annuloplasty ring in the corresponding area. Nevertheless, the technique of relocation itself is also varied in terms of relocating both papillary muscles or only posterior papillary muscles and the direction of relocating stitches to the anterior or posterior annulus. At present, it is known that mechanisms of functional MR are either from localized LV remodeling causing posterior papillary muscle displacement or global LV dilatation leading to both papillary muscles displacement and annular dilatation. Asymmetrical and symmetrical tethering patterns which demonstrate in echocardiograms as eccentric and central jets are the results of both mechanisms, respectively [16] [17]. For this reason, papillary muscle relocation should be applied in symmetrical tethering, whereas in asymmetrical tethering only posterior papillary muscle relocation could be done. Concerning the relocation site, direction to the anterior annulus could preserve diastolic mitral valve opening to avoid functional mitral stenosis according to a previous study [18]. Nevertheless, few studies reported good outcomes with the posterior realignment of papillary muscles and undersized ring annuloplasty [17] [19]. Relocation to the posterior annulus was used in this study as the technique was easier and caused fewer problems with the impingement on the 2^{nd} chordae. Moreover, during the follow-up period, the echocardiogram exhibited no diastolic problem with acceptable mitral valve area and gradient in this study. To adjust the length of the CV-4 suture, we gradually pulled the suture up under the full distension of LV with saline during arrested heart until there was some slightly upward movement of the coaptation point in the same region. As a result, the tension of the native chordae to the margin of both leaflets will decrease. There are some reports of adjusting the tension and length of the relocation suture during beating heart under intraoperative trans-esophageal echocardiogram guided. However, we are afraid that there would be a higher chance of cutting through the relocation stitches from the head of the papillary muscle as we must pull the sutures against the contraction of the heart.

Mitral deformity parameters include tenting depth > 1 cm, tenting area 2.5 cm^2 and posterior leaflet angle > 45 degree, which were considered as risk factors for recurrent MR, the secondary MR with tenting depth > 1 cm were included in this present study. The mean tenting area and PLA were approximately 2.59 cm^2 and 47 degrees. The severity of MR more than grade II was not found at the median follow-up of 33 months. Moreover, the improvement of mitral configuration and LV remodeling were also demonstrated at the mid-term follow-up. These favorable results could be the effect of adding relocating stitches which reduced tethering force and stabilize the further displacement of papillary muscles. On the contrary, solely undersized ring annuloplasty will push the posterior mitral annulus anteriorly causing more tethering force and more mitral deformity. These mechanisms can lead to recurrent MR at the follow-up time according to previous studies [20] [21].

There were some limitations in the study as it was a single center retrospective review, and the number of patients was still small. Some echocardiographic parameters such as anterior leaflet angle, interpapillary muscle distance and spherical index which are determined as other prognostic factors of recurrent MR, were not evaluated as they were not routinely measured in our institute. A future prospective randomized control trial with a greater number of patients included is needed to evaluate the long-term effect of combined undersized ring annuloplasty and papillary muscle relocation in 2^{nd} MR.

5. Conclusion

Adding papillary muscle relocation procedure to the undersized ring annuloplasty can improve clinical and echocardiographic outcomes in secondary MR at mid-term follow-up. Maintaining mitral geometry such as reducing tenting depth, tenting area and PLA could prevent recurrent moderate to severe mitral regurgitation as the effect of repositioning stitches in reducing tethering force.

Conflicts of Interest

The authors have no conflicts of interest to declare.

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