Original Article

Impact of Papillary Muscles Approximation on the Adequacy of Mitral Coaptation in Functional Mitral Regurgitation Due to Dilated Cardiomyopathy

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Purpose: We report early outcome of our modified papillary muscles approximation (PMA) as an adjunct to mitral annuloplasty (MAP) by analyzing the mitral coaptation zone echocardiographically and clinical outcome in three different procedures.
Methods: Mitral valve coaptation depth (MVCD) and tenting area were measured in patients with ischemic (n=8) or non-ischemic (n=22) dilated cardiomyopathy (ICM or non-ICM) undergoing either of following: Group I: isolated left ventricular volume reduction (LVVR) (n=11), Group II: PMA plus LVVR (n=14), Group III: isolated PMA (n=5). Clinical outcome including cardiac function were also investigated.
Results: Thirty-day mortality was 6.7%. Postoperative data in overall survivors showed significant improvement of ejection fraction (EF) (from 19±7 to 32±9%), left ventricular end-diastolic volume index (LVEDVI) (from 189±74 to 132±41 mL/m^2), and left ventricular diastolic dimension (LVDd) (from 73±8 to 65±6 mm) ($p<0.001$). The overall preoperative MVCD (mm) and tenting area (cm^2) was 10.4±2.8 and 2.4±0.6, respectively, which were both significantly reduced to 5.6±2.5 and 0.8±2.4 postoperatively ($p<0.001$). In comparison of the degree (%change) of improvement, Group II and III showed favorable effects on tethering force, compared with Group I.
Conclusion: Our modified PMA is a relatively safe method to have the potential for improving tethering of the mitral valve and clinical outcome in evaluating mitral coaptation zone. (Ann Thorac Cardiovasc Surg 2005; 11: 164–71)

Key words: dilated cardiomyopathy, papillary muscles, approximation, tethering

Introduction

It is widely noted that development of severe mitral regurgitation in ischemic or non-ischemic dilated cardiomyopathy (ICM or non-ICM) predicts a poor clinical outcome.[1-3] Functional mitral regurgitation occurring in dilated cardiomyopathy may result from dilation of the mitral annulus, laterally displaced papillary muscles, enhanced tethering force of the valve leaflets, and reduced closing force of the valve leaflets.[4-7] The mechanism of disease process is being elucidated and surgical procedure to relieve mitral regurgitation due to dilated cardiomyopathy has been reported previously.[8-14] Bolling et al.[8] reported that mitral annuloplasty (MAP) with an undersized flexible annuloplasty ring was beneficial for the increase in ejection fraction (EF) and cardiac output in severely dilated heart associated with mitral regurgitation. Calafiore et al.,[9,10] however, reported that isolated overcorrection of the mitral valve was unable to preclude the late recurrence of regurgitation when left ventricle (LV) dilation would recur in the late period.

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Papillary muscles approximation (PMA) has been recently reported as an adjunct to surgical coronary revascularization, undersized mitral ring annuloplasty, or left ventricular volume reduction (LVVR).[11-14] In these reports, PMA was undertaken to relieve functional mitral regurgitation by suppressing the lateral tethering and shortening the distance between the posterior LV wall and the papillary muscles. The purpose of this study is to report the early results of PMA on mitral regurgitation complicating dilated cardiomyopathy by analyzing echocardiographic outcome of mitral coaptation zone and clinical outcome in three different procedures; isolated PMR, PMR combined with LVVR, and isolated LVVR.

Patients and Methods

Between September 2001 and July 2004, 30 patients (25 male, 5 female, mean age 59±14 years) with dilated cardiomyopathy underwent either isolated LVVR (n=11), PMA combined with LVVR (n=14), or isolated PMA (n=5) as an initial surgical treatment. Overlapping cardiac volume reduction operation (OLCVR), which we have previously developed, was employed as a surgical procedure of LVVR.[11,15] Underlying disease were ICM for 8 and non-ischemic dilated cardiomyopathy for 22. Preoperative EF of all patients showed 20±8%, left ventricular end-diastolic volume index (LVEDVI) of 189±66 mL/m^2, and left ventricular diastolic dimension (LVDd) of 73±8 mm. All patients had echocardiographic evidence of mild (n=3), moderate (n=11) or severe (n=15) Carpentier type IIIb mitral regurgitation. The case of type I, II, IIIa was not contained in this study.

Preoperative risk factors included chronic renal failure for 5, including 4 patients who required hemodialysis periodically, daily steroid medication for 2, and hepatic and renal failure following preoperative profound shock for 1. Emergency surgery was performed for 4. Preoperative New York Heart Association (NYHA) functional class were III in 13 and IV in 17, including 9 cases of catecholamine dependent and 4 cases of intraaortic balloon pump (IABP) dependent.

All patients underwent MAP with an undersized artificial ring (Carpentier Physioring®; Edwards Corp, CA) of either 24M (n=2), 26M (n=22), or 28M (n=6) according to the physical constitution. No reconstruction of chordae/leaflet was performed. Concomitant procedures included aortic valve replacement in 5, tricuspid annuloplasty in 23, coronary artery bypass grafting (CABG) in 8, and MAZE procedure in 2 patients.

Isolated LVVR was performed mostly for early cases of dilated cardiomyopathy (Group I; n=11). For the late case, PMA combined with LVVR was first employed as a standard procedure (Group II; n=14). After confirming the effect of PMA in Group II, isolated PMR was undertaken for patients with moderate to severe mitral regurgitation with LVEDVI of 150 mL/m^2 or lower in the preoperative study or with LV volume of 90 mL/m^2 or lower measured with a sizer intraoperatively under cardiopulmonary bypass (CPB) in cases of ventriculotomy (Group III; n=5). There were no significant differences between the three groups in terms of age, preoperative NYHA functional class, EF, LVEDVI, and LVDd (Table 1).

Surgical technique

Informed consent was obtained before operation after full explanation. Prior to OLCVR and/or PMA, MAP with an undersized artificial ring was performed in all cases under blood cardioplegic arrest.

Group I; Isolated LVVR (Original OLCVR) : After MAP, a 10 cm long incision was made along the left anterior descending coronary artery in the enlarged LV free wall. The left incision marginal was then continuously sutured to the lower two-thirds of the septal wall. The right incision margin was attached to the epicardium to cover the ventricular free wall with pledgetted mattress sutures in non-ICM. In ICM, a felt strip was placed between the left incision margin and overlapped right incision margin. These procedures were followed by the proximal anastomosis of coronary revascularization or tricuspid annuloplasty, if necessary, after declamping of the aorta.

Group II; PMA combined with LVVR (Integrated OLCVR): More recently papillary muscles approximation (PMA) was carried out with 3 autologous pericardium pledgetted mattress sutures before ventriculoplasty through the LV incision. These sutures were placed through the trabeculae around the bases of the anterior and posterior muscles, the deepest being just below the site of chordal attachment. After PMA, the procedure of OLCVR described above was carried out.

Group III; Isolated PMA: PMA alone was carried out through a LV small incision (n=3), through aortotomy when the aortic valve had to be removed because of aortic regurgitation (n=1), and through the mitral valve by cutting the anterior leaflet margin (n=1) (Fig. 1).

Postoperative NYHA functional class and echocardiographic data, including EF, LVDd, LVEDVI, and the severity of mitral regurgitation, were compared with those

Table 1. Patient characteristics, preoperative hemodynamic data, operative procedures and preoperative risk factors

	I; LVVR (n=11)	II; PMA with LVVR (n=14)	III; PMA (n=5)	Total (n=30)
Age (year)	62±11	59±14	57±15	59±14
Gender (male/female)	11/0	7/7	4/1	25/5
Underlying disease (non-ischemic/ischemic cardiomyopathy)	11/0	7/7	4/1	22/8
NYHA functional class				
III	4	6	3	13
IV (catecholamine dependent)	7 (3)	8 (4)	2 (2)	17 (9)
EF (%)	18±10	20±6	23±7	20±8
LVEDVI (mL/m^2)	188±61	191±75	168±49	189±66
LVDd (mm)	71±8	74±8	73±7	73±8
Emergency surgery	2 (18%)	2 (14%)	0 (0%)	4 (13%)
Concomitant procedures				
AVR	1	2	2	5
TAP	7	11	5	23
CABG	1	7		8
MAZE procedure	2			2
Preoperative risk factor	5	1	2	8
Chronic renal failure (in need of hemodialysis)	3 (2)		2 (2)	5 (4)
Steroid medication	2			
Shock		1		

assessed preoperatively. In addition, mitral valve coaptation depth (MVCD) and tenting area of the mitral valve were also assessed by a four chamber view in patients whose mitral structure was accurately evaluable in each Group I to III (Fig. 2).[9,16]

All data for continuous variables are expressed as mean ± SD. Differences between preoperative and postoperative values were compared with paired *t* tests and Wilcoxon's rank test. A value *p* less than 0.05 was considered significant.

Results

Thirty-day mortality was 6.7% (2 patients). There was no cardiac death, but 2 patients undergoing emergency operation died of cerebral damage (n=1) and pneumonia (n=1) due to methicillin-resistant staphylococcus aureus infection. Seven patients required IABP support postoperatively, including 4 patients who had been dependent of IABP preoperatively. Percutaneous CPB support was required in one patient, who suffered a cardiac arrest preoperatively and underwent emergency operation (Table 2). No patient needed ventricular assist device postoperatively. Serious ventricular arrhythmias were not seen postoperatively, except in one patient who had received implantation of an implantable defibrillator preoperatively and was finally treated successfully with several antiarrhythmic agents postoperatively. The mean NYHA functional class in overall survivors was significantly improved from 3.6±1.6 preoperatively to 1.4±0.9 postoperatively (p<0.001). Significant improvement of NYHA functional class was noted in all three groups. Postoperative hemodynamic data in overall survivors showed a significant improvement of EF (from 19±7 to 32±9%) , LVEDVI (from 189±74 to 132±41 mL/m^2), and LVDd (from 73±8 to 65±6 mm) (p<0.001 vs. preoperative EF, LVDd, and LVEDVI. Data from those with preoperative catecholamine dependent were excluded). In comparison of pre- and postoperative hemodynamic data between each group, all groups showed significant improvement of EF and LVEDVI postoperatively, whereas reduction in the LVDd was insignificant in Group I (Table 3).

The severity of mitral regurgitation was mild in 4, moderate in 11 and severe in 15 preoperatively, which was downgraded in all cases postoperatively to none-to-trace in 28, and mild in 2. At a mean follow-up of 11±9 months, no patient showed deterioration of mitral regurgitation, except one patient of Group II whose mitral regurgitation had deteriorated from mild to moderate associated with recurrence of LV dilation 6 months after operation.

The mean MVCD was 10.4±2.8mm preoperatively. Patients with a MVCD of 11 or more (mm) comprised 64% (n=14) of the 22 patients evaluated. In comparison between pre- and postoperative MVCD data in each group, all three groups showed a significant reduction in MVCD postoperatively. The most remarkable reduction in MVCD among the three groups was found in Group II, those un-

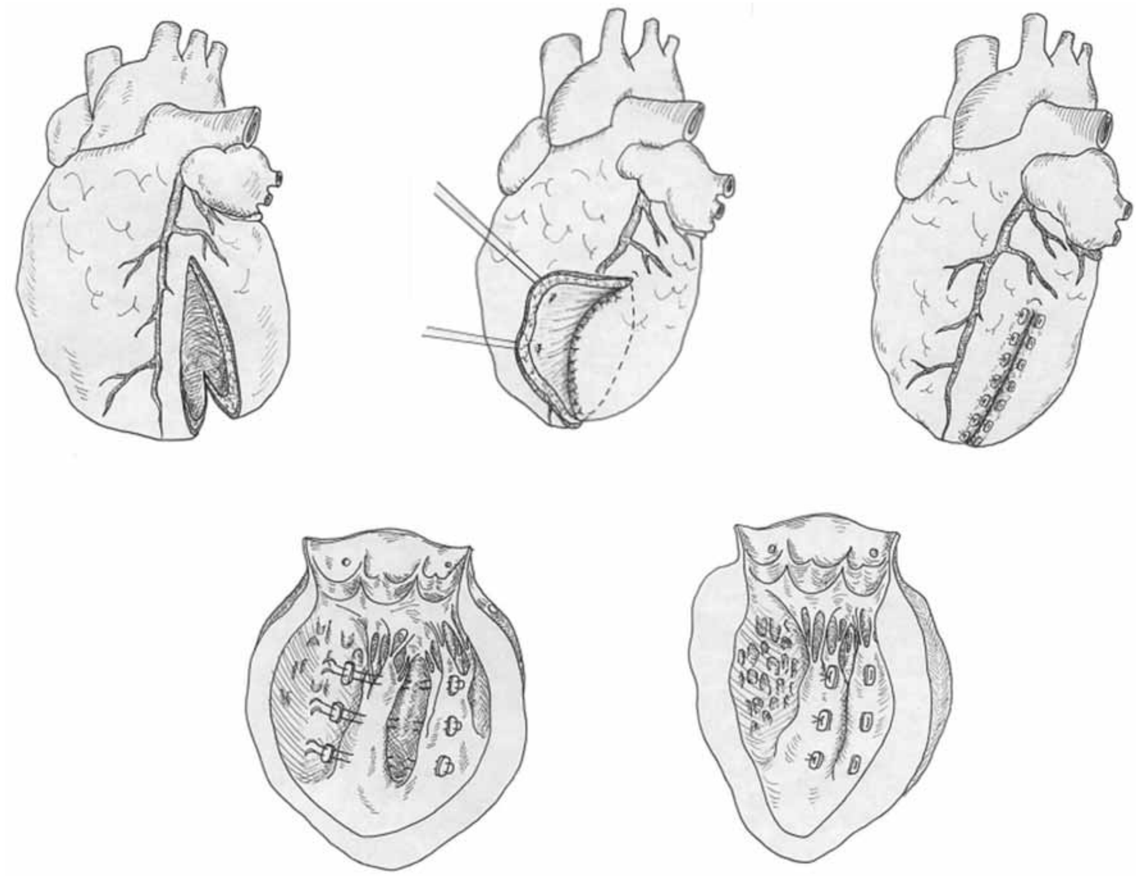

Fig. 1. Operative procedure of our left ventricle volume reduction (LVVR) (overlapping cardiac volume reduction operation (OLCVR)) and papillary muscles reapproximation. Note that reapproximation was performed over the whole length of the papillary muscles.

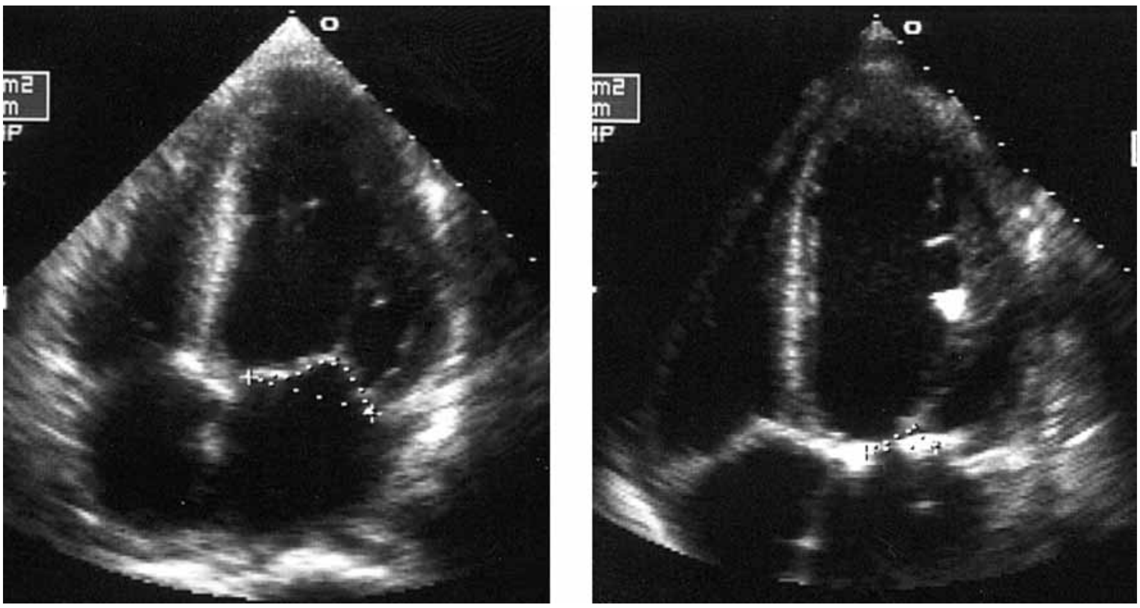

Fig. 2. Four chambers view of echocardiography assessing pre- and postoperative mitral valve coaptation depth (MVCD) and tenting area . Preoperative (left) and postoperative (right) view of a case in isolated PMA group.

Table 2. Operative results

	I; LVVR (n=11)	II; PMA with LVVR (n=14)	III; PMA (n=5)	Total (n=30)
Postoperative use of mechanical circulatory support	4 (2)	3 (2)	0	7 (4)
IABP (since preoperatively)				
PCPS	0	1	0	1
VAD	0	0	0	0
Early mortality	2 (18%)	0 (0%)	0 (0%)	2 (7%)
Cause of early deaths				
Sepsis	1*			
Cerebral damage	1*			
Discharge on foot	9 (82%)	11 (79%)	5 (100%)	25 (83%)
Late mortality	4 (36%)	2 (14%)	0 (0%)	6 (20%)
Cause of late deaths				
Heart failure	2			
Sepsis	2**			
Cerebral damage		1*		
Renal failure		1*		
NYHA functional class				
Preoperative	3.6±0.5	3.6±0.5	3.8±0.4	3.6±0.6
Postoperative	1.4±0.8	1.5±0.8	1.4±0.5	1.4±0.9
p value	<0.001	<0.001	<0.001	<0.001

*Emergency operation cases, **Steroid medication cases.

Table 3. Hemodynamic data in selected comparative cases

	I; LVVR (n=9)	II; PMA with LVVR (n=8)	III; PMA (n=5)	Total (n=22)
EF(%)				
pre	17±7	20±2	23±8	19±7
post	29±10	34±6	35±13	32±9
p value	<0.001	<0.01	<0.05	<0.001
LVEDVI (mL/m^2)				
Preoperative	184±64	208±107	176±53	189±74
Postoperative	128±32	128±59	143±39	132±41
p value	<0.05	<0.05	<0.05	<0.001
LVDd (mm)				
Preoperative	71±9	75±7	73±7	73±8
Postoperative	64±5	67±8	64±4	65±6
p value	ns	<0.01	<0.01	<0.001

dergoing PMA combined with LVVR. The postoperative tenting area also showed a significant reduction compared to the preoperative tenting area in each group. The degree of improvement was significantly better in patients undergoing PMA combined with LVVR or isolated PMA, compared with those receiving isolated LVVR (Table 4).

Discussion

Mitral regurgitation is known to predict a poor prognosis in patients with ICM or non-ICM.[1-3] Functional mitral regurgitation occurring in a severely dilated heart may result from the intricate mechanism including dilation of the mitral annulus, laterally displaced papillary muscles, enhanced tethering force of the valve leaflets, and reduced closing force of the valve leaflets.[4-7] Among these factors, tethering of the mitral valve was reported to be mainly responsible for the development of severe functional regurgitation.[5-7] It was also reported that ischemic mitral regurgitation was induced by exercise, the severity of which was unrelated to the degree of mitral regurgitation at rest.[17] Thus caution should be employed in mitral valve surgery in patients with dilative cardiomyopathy when surgical indication is decided depending upon the degree of mitral regurgitation at rest. During the long-term follow-up after ventriculoplasty or MAP, LV dilation may recur and worsen the tethering of the mitral valve that causes recurrence of mitral regurgitation.[18-20] To reduce

Table 4. Effects on tethering force in comparative cases

	I; LVVR (n=9)	II; PMA with LVVR (n=8)	III; PMA (n=5)	Total (n=22)	*p* value		
					I vs II	I vs III	II vs III
Mitral valve coaptation depth (mm)							
Preoperative	9.3±2.7	10.2±2.8	12.8±1.6	10.4±2.8	ns	<0.05	ns
depth ≥ 11 mm	4/9	5/8	5/5	14/22			
Postoperative	7.0±1.8	3.5±1.1	6.4±3.2	5.6±2.5	<0.001	ns	<0.05
%change	21±21	64±13	48±26	43±23	<0.001	ns	ns
p value	<0.05	<0.001	<0.05	<0.001			
Tenting area (cm^2)							
Preoperative	2.4±0.7	2.5±0.7	2.5±0.5	2.4±0.6	ns	ns	ns
Postoperative	1.0±0.3	0.5±0.2	0.8±0.5	0.8±0.4	<0.001	ns	ns
%change	43±11	80±9	68±14	62±20	<0.001	<0.01	ns
p value	<0.001	<0.001	<0.001	<0.001			

*ns; non-significant

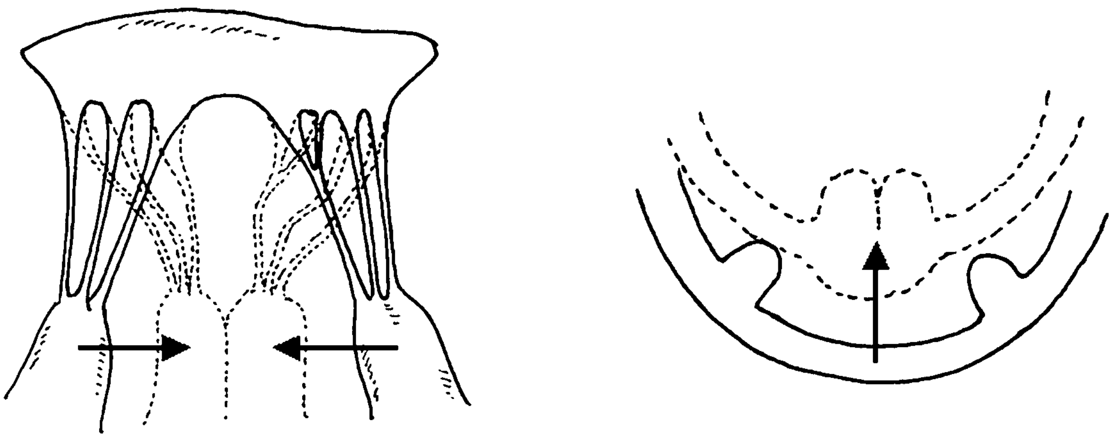

Fig. 3. Concepts of mechanism of PMA on tethering force. PMA side-by-side over the whole length is performed to suppress the lateral tethering (left). LV posterior wall between the papillary muscles is shortened as a result of the surgical remodeling, which also reduces the backward tethering (right).

tethering force and improve coaptation of the mitral valve, forward compression of the LV posterior wall from the outside[21] or cutting a minimum number of basal chordae has been reported.[22]

It is well recognized that functional mitral regurgitation could be abolished by annular size reduction most effectively.[23] Bolling et al.[8] reported the effectiveness of MAP with an undersized flexible annuloplasty ring on the improvement of cardiac function through geometric reconstruction in the severely dilated heart associated with mitral regurgitation. Calafiore et al., however, reported that isolated overcorrection of the mitral valve had the potential for recurrence of regurgitation when LV would dilate again in the late period.[9,10] They also advocate the use of MVCD in the choice of surgical strategy on the mitral valve; for example, they recommend that valve replacement whilst preserving subvalvular tissue should be chosen when preoperative MVCD was 11 mm or higher. Since we have previously experienced cases of mitral regurgitation recurrence similar to them and most surgeons prefer mitral valve reconstruction than replacement,[24,25] PMA side-by-side over the whole length is performed to suppress the lateral tethering. LV posterior wall between the papillary muscles is shortened as a result of the surgical remodeling, which also reduces the backward tethering as described above (Fig. 3).

The procedure of PMA similar to that presented here has been reported by Nair and Menicanti et al.,[12,14] which was however aimed at posterior LV volume reduction and exclusion of ischemic scarred wall. The extent of PMA was different from our procedure performed over the whole length of the papillary muscles to prevent late recurrence of mitral regurgitation. Hvass et al.[13] reported the procedure of trans-annular papillary muscle sling using a 4-mm Gore-Tex tube. Their procedure is limited to the intermediate portion of papillary muscles, which is unlikely to improve tethering toward the apex.

For the assessment of the efficacy of PMA, MVCD and the tenting area measured preoperatively were compared with those postoperatively in this study.[9,16] The tenting area is likely to be more useful in evaluating coaptation zone pre- and postoperatively. In comparison of MVCD and the tenting area in each group, all three groups showed a significant improvement of MVCD and the tenting area postoperatively. The most marked improvement of MVCD and the tenting area among the three groups was seen in those undergoing PMA combined with LVVR. It is not clear about the extent to which MAP alone contributed to improving MVCD and the tenting area in this study. However in comparison of isolated LVVR and PMA combined with LVVR on the tethering force, the addition of PMA may have beneficial effects to some extent on the tethering force. On the other hand, no significant difference was noted in the degree of improvement (%change) of MVCD and the tenting area between isolated PMA and PMA combined with LVVR. The effects on tethering produced by isolated PMA and PMA combined with LVVR are almost comparable, thus the addition of LVVR to PMA may not be necessary unless the LV cavity is extremely enlarged.

Isolated PMA was performed mostly through a small incision of the LV wall but was accomplished without ventriculotomy in some cases through the aortic root when the aortic valve had to be removed because of regurgitation, and through the mitral annulus by cutting the anterior leaflet margin. The current indication for isolated PMA based on limited experiences in our institute is as follows: 1) presence of moderate to severe functional mitral regurgitation with LVEDVI of 150 or lower in the preoperative study, 2) LV volume of 90 mL/m^2 or lower measured by an ellipsoidal sizer intraoperatively under CPB in case of ventriculotomy, and 3) absence of apparent akinetic or dyskinetic area of anterior LV wall.

Although limitation exists in evaluating operative results due to the shortage of the number of operations, lack of comparison with isolated MAP, and lack of long-term follow-up, we consider PMA over the whole length of papillary muscles to be a promising method that may improve surgical results for cardiac failure in the severely dilated heart. Further study is required to determine the indication of PMA combined with OLCVR and whether this favorable modification of left ventricular function and geometry will persist.

Conclusion

Our modified procedure of PMA over the whole length of the papillary muscle is a relatively safe method to have the potential for improving tethering of the mitral valve and clinical outcome. This procedure for functional mitral regurgitation is expected to be an effective therapy comparable to PMA plus LVVR for selected cases of severely dilated heart. Further study is required as to whether this favorable modification of papillary muscles and geometry will persist and contribute to significantly improving clinical outcome. Preliminary operative results are promising, and a comparative study on long-term follow-up is warranted.

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