Papillary muscle relocation in conjunction with valve annuloplasty improve repair results in severe ischemic mitral regurgitation

Khalil Fattouch, MD, PhD,^a Patrizio Lancellotti, MD, PhD,^b Sebastiano Castrovinci, MD,^a Giacomo Murana, MD,^a Roberta Sampognaro, MD,^c Egle Corrado, MD,^d Marco Caruso, MD, PhD,^d Giuseppe Speziale, MD,^c Salvatore Novo, MD,^d and Giovanni Ruvolo, MD^a

Objective: The incidence of recurrent mitral regurgitation (MR) after restrictive annuloplasty (RA) was 5% to 20% in several reports. There are many opinions in favor of adding subvalvular procedures to RA to reduce the tenting forces and improve the repair results.

Methods: From March 2003 to May 2010, 55 patients with severe ischemic MR who had undergone papillary muscle (PPM) relocation in conjunction with mitral annuloplasty in our institutions were enrolled. The patients were matched 1:1 with those who underwent isolated RA using the propensity score. The mean left ventricular ejection fraction was $42\% \pm 6\%$. The mean tenting area and coaptation depth was $3.2 \pm 0.6 \text{ cm}^2$ and $1.3 \pm 0.2 \text{ cm}$, respectively. The study endpoints were early mortality and clinical and echocardiographic outcomes, freedom from cardiac-related deaths, and cardiac-related events.

Results: In-hospital death occurred in 5 patients (4.5%), without a statistically significant difference between the 2 groups ($P = .72$). The 5-year freedom from cardiac-related deaths and cardiac-related events in the PPM relocation group versus the RA group was $90.9\% \pm 1.8\%$ versus $89\% \pm 1.6\%$ ($P = .82$) and $83\% \pm 2.1\%$ versus $65.4\% \pm 1.2\%$ ($P < .001$), respectively. Recurrent MR equal to or greater than moderate occurred in 2 (3.7%) and 6 (11.5%) patients in the PPM relocation group and RA group ($P = .01$), respectively. Moreover, we found statistically significant differences for the postoperative mean tenting area and coaptation depth in both groups ($P < .001$).

Conclusions: PPM relocation in conjunction to mitral annuloplasty is an easy and safe method and can be performed without an increase in-hospital mortality. This technique reduced the tenting area and coaptation depth compared with isolated RA, leading to improvement in the incidence of recurrent MR. The PPM group of patients experienced fewer cardiac-related events. (J Thorac Cardiovasc Surg 2012;143:1352-5)

Currently, there is general agreement about the efficacy of the surgical treatment for patients with severe ischemic mitral valve regurgitation (IMR) but the best surgical approach is still in conflict.¹ Many investigators advocated mitral valve restrictive annuloplasty (RA), meanwhile others have suggested mitral valve replacement.²⁻⁶ Investigators supporting a conservative approach believe that conservation of the continuity between the valve and left ventricle lead to better long-term results and a reverse in left ventricular (LV) remodeling.^{3,7} In contrast, many surgeons prefer mitral valve replacement using a biologic

prosthesis with subvalvular apparatus conservation to avoid recurrent MR. The incidence of recurrent MR after isolated RA was 5% to 20% in several reports.^{8,9} There are many opinions in favor of adding subvalvular procedures to mitral annuloplasty (MA) to reduce the tenting forces and improve the long-term repair results.¹⁰ The aim of our study was to compare the results of both approaches, papillary muscle (PPM) relocation and MA with isolated RA.

MATERIALS AND METHODS

Patients

From March 2003 to May 2010, 55 patients with severe IMR (effective regurgitant orifice area, $\geq 20 \text{ mm}^2$) who underwent PPM relocation in conjunction with MA and coronary artery bypass grafting (CABG) were enrolled. The patients were matched 1:1 with patients who underwent isolated RA and CABG (using the propensity score) to obtain 2 groups with similar preoperative characteristics. The variables chosen for the matching process were the number of diseased vessels, LV ejection fraction, type of myocardial infarction (MI), New York Heart Association (NYHA) functional class, congestive heart failure, atrial fibrillation, coaptation depth, tenting area, and interpapillary distance. All patients with IMR had restrictive systolic leaflet motion (Carpentier's type IIb) and annular dilation. MR was defined as ischemic when caused by coronary artery disease in patients who had a previous MI, 2 weeks or more before hospital admission for CABG and exhibited normal valve apparatus anatomy. The exclusion criteria were PPM infarction causing its rupture or elongation,

From the Department of Cardiac Surgery,^a University of Palermo, Palermo, Italy; Heart Valve Clinic,^b University of Liège, Department of Cardiology, CHU Sart Tilman, Liège, Belgium; Department of Cardiology and Cardiac Surgery,^c GVM Care and Research, Palermo and Bari, Italy; and Department of Internal Medicine and Cardiovascular Diseases,^d University of Palermo, Palermo, Italy.

Disclosures: Authors have nothing to disclose with regard to commercial support.

Presented at the American Association for Thoracic Surgery Mitral Conclave, New York, New York, May 5-6, 2011.

Received for publication May 14, 2011; revisions received Sept 14, 2011; accepted for publication Sept 28, 2011; available ahead of print Nov 4, 2011.

Address for reprints: Khalil Fattouch, MD, PhD, Department of Cardiac Surgery, University of Palermo, Via Liborio Guffrè 5, Palermo 90127 Italy (E-mail: khalilfattouch@hotmail.com).

0022-5223/\$36.00

Copyright © 2012 by The American Association for Thoracic Surgery

doi:10.1016/j.jtcvs.2011.09.062

Abbreviations and Acronyms

CABG	= coronary artery bypass grafting
IMR	= ischemic mitral valve regurgitation
LV	= left ventricular
MA	= mitral (valve) annuloplasty
MI	= myocardial infarction
NYHA	= New York Heart Association
PPM	= papillary muscle
RA	= restrictive annuloplasty

recent MI (<15 days), concomitant aortic valve surgery, or organic mitral valve lesions (rheumatic, infective, degenerative), and surgical restoration of the left ventricle. The institutional review board of our university approved the study. The authorization waived patient consent. The baseline patient characteristics are listed in Table 1.

Study Endpoints

The study endpoints were as follows: the incidence of early mortality and outcomes, freedom from late cardiac-related deaths and cardiac-related events, NYHA functional class, and reverse LV remodeling. Cardiac events were defined as the occurrence of at least 1 of the following: cardiac death, MI, congestive heart failure, redo on mitral valve, revascularization (CABG or percutaneous intervention), new-onset atrial fibrillation, worsening in NYHA functional class, recurrent MR equal to or greater than moderate, and hospital re-admission.

Surgical Technique

All patients underwent conventional multivessel CABG through a full midline sternotomy under normothermic cardiopulmonary bypass with intermittent antegrade cold-blood cardioplegia. For every patient, the bypass grafts used were the internal thoracic artery and the long saphenous vein. All distal anastomoses were performed during a single aortic cross-clamping. The proximal graft anastomoses were performed during side clamping.

MA was performed using a Carpentier-Edwards physio ring (Edwards Life Sciences, Irving, Calif) or the Saddle Rigid ring (St. Jude Medical, Minneapolis, Minn). The ring size was determined according to the surface of the anterior leaflet. Regarding the “restrictive annuloplasty” group, we used a ring with a surface 2 sizes less than anterior leaflet surface. In the “relocation PPM” group, we did not use a smaller size but the normal size. We believe that in patients who undergo PPM relocation, the use of a ring according to the anterior leaflet surface should be effective without having to use undersizing. The rings were inserted using deep horizontal U sutures and Ticron 2-0 suture (Syneture, Norwalk, Conn).

PPM relocation was performed using a CV-4 Gore-Tex suture (W. L. Gore and Associates, Flagstaff, Ariz) placed first at the head of each PPM and subsequently through the ipsilateral mitral annulus, during an arrested heart, in accordance with the technique described by Kron and colleagues.¹⁰ We relocated both PPMs to minimize mitral valve tenting (Figure 1). Usually, 1 head of the anterior PPM was relocated. However, among the 3 heads of the posterior PPM, we relocated the anterior and posterior ones. It is very important to relocate both heads of the posterior PMs, because from the anterior PM arises the chordae for the anterior leaflet responsible for the seagull sign and respective tenting and from the posterior PM arises the chordae to the posterior leaflet (P2 and P3 scallops).

All patients underwent postoperative transesophageal echocardiography of the left ventricle and valve function. Mitral valve repair was

TABLE 1. Baseline, intraoperative characteristics, outcomes, and follow-up data

Variable	PPM relocation plus MA	RA	P value
Mean age (y)	62 ± 12	62 ± 8	.91
Male gender	32 (58)	34 (61.8)	.82
Diabetes mellitus	15 (27.2)	14 (25.5)	.81
Chronic obstructive pulmonary disease	6 (11)	5 (9)	.75
Hypertension	28 (51)	31 (56.3)	.53
Renal failure*	5 (9)	7 (12.7)	.62
Unstable angina	14 (25.5)	13 (23.6)	.81
Congestive heart failure	16 (29)	15 (27.2)	.78
Atrial fibrillation	3 (5.4)	4 (7.2)	.36
NYHA class >II	17 (31)	16 (29)	.77
Side of previous MI			
Anterior	13 (23.6)	13 (23.6)	1.0
Inferior	38 (69)	36 (65.4)	.68
Both	6 (11)	8 (14.5)	.55
Echocardiographic data			
Mean tenting area	3.2 ± 0.9	3.2 ± 0.2	.81
Mean coaptation depth	1.3 ± 0.1	1.3 ± 0.3	.76
LVEDD (mm)	58 ± 8	58 ± 2	.97
LVESD (mm)	48 ± 1	48 ± 4	.81
Mean LVEF (%)	42 ± 8	42 ± 5	.89
Perioperative data			
CPB time (min)	115 ± 30	108 ± 35	.08
Aortic crossclamp time (min)	86 ± 18	84 ± 15	.12
Grafts/patient	2.9 ± 0.4	2.8 ± 0.6	.36
Bleeding	3 (5.4)	2 (3.6)	.76
Renal failure (dialysis)	2 (3.6)	2 (3.6)	1.0
LCOS	1 (1.8)	2 (3.6)	.51
Sepsis	0	1 (1.8)	—
In-hospital mortality	2 (3.6)	3 (5.4)	.72
Follow-up data			
NYHA class >II	2 (3.7)	3 (5.7)	.71
Hospital readmission for CHF	2 (3.7)	7 (13.4)	.01
Recurrent MR moderate or greater	2 (3.7)	6 (11.5)	.02
Mean tenting area (cm ²)	1.2 ± 0.3	2.3 ± 0.4	<.001
Mean coaptation depth	0.6 ± 0.2	1 ± 0.2	<.001
LVEDD (mm)	50 ± 7	54 ± 8	.02
LVESD (mm)	40 ± 8	44 ± 5	.02
Mean LVEF (%)	46 ± 5	45 ± 4	.21

Data presented as mean ± SD or number (%). CPB, Cardiopulmonary bypass; LCOS, low cardiac output syndrome; LVEDD, left ventricular end-diastolic diameter; LVEF, left ventricular ejection fraction; LVESD, left ventricular end-systolic diameter; MA, mitral annuloplasty; MI, myocardial infarction; MR, mitral regurgitation; NYHA, New York Heart Association; PPM, papillary muscle; RA, restrictive annuloplasty. *Serum creatinine >1.5 mg/dL.

considered successful if no or trivial residual MR was present and the coaptation surface was about 0.8 cm.

Clinical and Echocardiographic Follow-up

All patients were followed up by our cardiologists at 6-month intervals. The pre- and postoperative clinical status was determined according to the criteria of the NYHA functional class and the Canadian Cardiovascular Society for heart failure symptoms and angina,

FIGURE 1. Schematic representation of papillary muscle (PPM) relocation.

respectively. Clinical follow-up data were obtained for all patients and were 100% complete. The follow-up period started September 2010 and ended November 2010. The mean follow-up period was 32 ± 12 months.

Statistical Analysis

The numeric values are presented as the mean $\pm$ standard deviation. The frequency ratios are given as percentages. Continuous variables were compared between the 2 groups using Student's unpaired *t* test. The frequency ratios between the 2 groups were compared using the χ^2 test. Stepwise logistic regression analysis was used to realize a model to calculate the propensity score. The LV end-diastolic diameter, LV end-systolic diameter, and LV ejection fraction were analyzed using the paired *t* test and Wilcoxon signed rank test. Variables were put into a Cox regression model. Where appropriate, hazard ratios were computed with the 95% confidence intervals. The actuarial survival and other time-related events were analyzed using the Kaplan-Meier method. The log-rank test was used to compare the statistical significance level. $P < .05$ was considered statistically significant. The Statistical Package for Social Sciences statistical software (SPSS, Chicago, Ill) was used.

RESULTS

No statistically significant difference was found between the 2 groups for the preoperative demographics or clinical and echocardiographic characteristics owing to the matching process. No statistically significant difference was found between the 2 groups for the intraoperative data (Table 1).

Early Outcomes

In-hospital deaths for the entire population occurred in 5 patients (4.5%), without a statistically significant difference between the 2 groups ($P = .72$). Two (3.6%) and three (5.4%) patients died in the PPM relocation group and isolated RA group, respectively. The causes of in-hospital death were low cardiac output in 3 patients, sepsis in 1, and multiorgan failure in 1. Intra-aortic balloon pump implantation was necessary to treat postoperative cardiogenic shock in 3 patients (2.7%).

Late Mortality and Outcomes

The overall 5-year freedom from cardiac-related death rate in the PPM relocation group and the isolated RA group was $90.9\% \pm 1.8\%$ and $89\% \pm 1.6\%$ ($P = .82$), respectively (Figure 2, A). Late cardiac deaths occurred in 6 patients (5.7%). The causes of late death were congestive heart failure in 3 patients, arrhythmias in 2, and sudden death in 1. The following independent variables for late mortality in the entire population were found on Cox analysis: LV ejection fraction of 30% or less (hazard ratio, 9; 95% confidence interval, 2.1–36; $P = .004$) and NYHA class of III or greater (hazard ratio, 5.6; 95% confidence interval, 1.6–42; $P = .007$).

The 5-year freedom from cardiac-related event rate in the PPM relocation group and isolated RA group was $83\% \pm 2.1\%$ and $65.4\% \pm 1.2\%$ ($P < .001$), respectively (Figure 2, B).

At follow-up, the NYHA functional class improved from 2.6 ± 1.1 to 1.4 ± 0.3 ($P = .021$) in the PPM relocation group and 2.5 ± 0.9 to 1.6 ± 0.4 ($P = .026$) in the isolated RA group.

FIGURE 2. Kaplan-Meier log-rank test used to compare (A) cardiac-related deaths and (B) cardiac-related events among 2 groups.

Echocardiographic Data at Follow-Up

Recurrent MR equal to or greater than moderate occurred in 2 (3.7%) and 6 (11.5%) patients in the PPM relocation group and RA group, respectively ($P = .01$).

Reversal in LV remodeling measured by a change in the LV end-diastolic diameter and LV end-systolic diameter was significantly observed in both group compared with baseline, but the PPM relocation approach promoted a significant reversal in LV remodeling compared with the isolated RA approach (Table 1).

The postoperative mean tenting area was $1.2 \pm 0.3 \text{ cm}^2$ and $2.3 \pm 0.4 \text{ cm}^2$ for the PPM relocation and RA groups, respectively ($P < .001$). The postoperative mean coaptation depth was $0.6 \pm 0.2 \text{ cm}$ and $1.1 \pm 0.2 \text{ cm}$ in the PPM relocation and RA groups, respectively ($P < .001$).

DISCUSSION

Although the surgical treatment of severe IMR in patients presenting for CABG is recommended by the American College of Cardiology/American Heart Association guidelines,¹ the best surgical approach is still being debated. Several clinical studies have provided only limited information about the dilemma to repair or replace the mitral valve in patients with severe IMR.^{4,6} This conflicting decision is mainly affected by the lack of prospective studies and, often, by the comparison of clinical outcomes for both procedures in dissimilar patient groups. Evidence is awaited from a current randomized study (evaluation of outcomes following mitral valve repair/replacement in severe chronic ischemic mitral regurgitation; available from: www.ctsurgery.net/SMRAbstract.html). Investigators favoring a conservative approach believe that undersizing with MA improves the early and late clinical outcomes and leads to reversal in LV remodeling.^{2,3,5,7} However, the incidence of recurrent MR in patients who have undergone isolated RA has been up to 20% to 30%.^{8,9} In contrast, replacement of the mitral valve by a bioprosthesis with conservation of the subvalvular apparatus eliminates the incidence of MR recurrence but leads to the risk of prosthesis valve-related events.

Currently, RA is still associated with poor outcomes in many series, probably for different reasons. First, wide heterogeneity exists in published reports regarding the type of prosthetic ring (complete, band, rigid, flexible, pericardium) used by surgeons for MA that inevitably leads to different results. Second, RA was performed in all patients with IMR, regardless of the degree of LV dysfunction and dilation and the severity of mitral valve tenting and PPM displacement. Thus, surgeons routinely perform RA as a unique surgical solution for a complex LV disease.

Recently, several investigators proposed different surgical techniques (posterior LV wall plication, PPM relocation,

LV reconstruction, second chordae cutting, and so forth) to add to MA to improve the long-term repair results. In the present series, we report our experience with PPM relocation. This technique was first introduced by Kron and colleagues,¹⁰ and we believe is easy and reproducible. In our series, PPM relocation was performed with low early and late mortality. However, the patients who underwent PPM relocation plus MA experienced fewer late cardiac-related events than those who underwent isolated RA ($P < .001$). Moreover, the incidence of recurrent MR was greater in the RA group.

LV reverse remodeling has previously been observed after restrictive MA.^{3,7} In the present series, we found that PPM relocation reduce the LV end-diastolic diameter ($P = .02$) and LV end-systolic diameter ($P = .02$) more than did RA. However, it is not clear whether PPM relocation can have a favorable effect on LV reverse remodeling compared with isolated RA. We suggest that PPM relocation can reduce the tenting area and coaptation depth better and probably avoid additional displacement of the PPMs.

In conclusion, PPM relocation is a safe method. This technique reduce the tenting area and coaptation depth compared with isolated RA, leading to a low incidence of recurrent MR. Moreover, we found that PPM relocation promotes better reverse LV remodeling compared with isolated RA.

References

1. Bonow RO, Carabello BA, Chatterjee K, et al. American College of Cardiology/American Heart Association Task Force on Practice Guidelines. ACC/AHA 2006 Guidelines for the Management of Patients With Valvular Heart Disease. *JACC*. 2006;48:1-148.
2. Bolling SF, Deeb GM, Brunsting LA, Bach DS. Early outcome of mitral valve reconstruction in patients with end-stage cardiomyopathy. *J Thorac Cardiovasc Surg*. 1995;109:676-82.
3. Fattouch K, Guccione F, Sampognaro R, et al. Efficacy of adding mitral valve restrictive annuloplasty to CABG in patients with moderate ischemic mitral valve regurgitation: a randomised trial. *J Thorac Cardiovasc Surg*. 2009;138:278-85.
4. Gillinov AM, Wierup PN, Blackstone EH, et al. Is repair preferable to replacement for ischemic mitral regurgitation? *J Thorac Cardiovasc Surg*. 2001;122:1125-41.
5. Adams DH, Chen RH, Byrne JG, et al. Improving outcomes in patients with moderate ischemic mitral regurgitation undergoing combined CABG and mitral annuloplasty. *Circulation*. 2000;102(Suppl II):II-462.
6. Vassileva CM, Boley T, Markwell S, Hazelrigg S. Meta-analysis of short-term and long-term survival following repair versus replacement for ischemic mitral regurgitation. *Eur J Cardiothoracic Surg*. 2011;39:295-303.
7. Bax JJ, Braun J, Somer ST, et al. Restrictive annuloplasty and coronary revascularization in ischemic mitral regurgitation results in reverse left ventricular remodeling. *Circulation*. 2004;110(Suppl II):II-103-8.
8. Kuwahara E, Otsuji Y, Iguro Y, et al. Mechanism of recurrent/persistent ischemic/functional mitral regurgitation in chronic phase after surgical annuloplasty: importance of augmented posterior leaflet tethering. *Circulation*. 2006;114:1-529-34.
9. Mihaljevic T, Lam BK, Rajeswaran J, et al. Impact of mitral valve annuloplasty combined with revascularization in patients with functional ischemic mitral regurgitation. *JACC*. 2007;49:2191-201.
10. Kron IL, Randall Green G, Cope JT. Surgical relocation of the posterior papillary muscle in chronic ischemic mitral regurgitation. *Ann Thorac Surg*. 2002;74:600-1.