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Mitral Valve Repair With Carpentier-McCarthy-Adams IMR ETlogix Annuloplasty Ring for Ischemic Mitral Regurgitation

Early Echocardiographic Results From a Multi-Center Study

Masao Daimon, MD; Shota Fukuda, MD; David H. Adams, MD; Patrick M. McCarthy, MD; A. Marc Gillinov, MD; Alain Carpentier, MD; Farzan Filsoofi, MD; Vivian M. Abascal, MD; Vera H. Rigolin, MD; Sacha Salzberg, MD; Anna Huskin, RN; Michelle Langenfeld, RN; Takahiro Shiota, MD

Background—Ischemic mitral regurgitation (IMR) is associated with asymmetric changes in annular and ventricular geometry. Surgical repair with standard symmetric annuloplasty rings results in a high incidence of residual or recurrent mitral regurgitation (MR). The Carpentier-McCarthy-Adams (CMA) IMR ETlogix annuloplasty ring is the first remodeling ring specifically designed to treat asymmetric leaflet tethering and annular dilatation. We used quantitative 2-dimensional echo to examine early results of mitral valve (MV) repair with the CMA IMR ETlogix annuloplasty ring in patients with IMR.

Methods and Results—Fifty-nine patients (aged 68 ± 12 years) with grade $\geq 2+$ IMR (graded on a scale of 0 to 4+) underwent MV repair with the CMA IMR ETlogix annuloplasty ring. We assessed the mitral annular diameter (MAD), tethering area (TA), and tenting height (TH) of the MV in 4-chamber, 2-chamber, and long axis views at mid-systole before and 3 to 10 days after surgery. After surgery, 57 of 59 (97%) patients had grade 0 or 1+ MR, whereas 2 patients had 2+ MR. MV repair with the CMA IMR ETlogix ring significantly reduced MAD, TA, and TH ($P < 0.001$, for all 3 echo views), particularly in the long axis and 4-chamber views.

Conclusion—Surgical repair of IMR with the novel asymmetric CMA IMR ETlogix annuloplasty ring provided excellent early results with effective reduction of MR, MAD, and leaflet tethering. This novel etiology-specific strategy may result in improved outcomes in IMR patients. (*Circulation*. 2006;114[suppl I]:I-588–I-593.)

Key Words: echocardiography ■ mitral valve ■ myocardial infarction ■ regurgitation

Ischemic mitral regurgitation (IMR) occurs in up to 19% of patients after myocardial infarction (MI)^{1,2} and is an independent predictor of mortality.³ Although some evidence suggests that surgical mitral annuloplasty has a beneficial effect on prognosis in patients with IMR, surgical repair with standard, symmetric, flat annuloplasty rings may leave up to 30% of patients with residual or recurrent mitral regurgitation (MR).^{4–6} The important impact of IMR on survival should challenge surgeons to make every effort to minimize residual MR after mitral annuloplasty. Therefore, new surgical strategies are necessary to improve the treatment for IMR.

IMR has a complex pathophysiology that includes alterations in the geometry and function of the left ventricle (LV), subvalvular apparatus, and mitral annulus.^{7–12} The most common mechanism of IMR is restricted leaflet motion, particularly the posterior leaflet during systole (Carpentier's

type IIIb dysfunction¹³). Recently, it was demonstrated that, in IMR, the pattern of mitral valve (MV) deformation from the postero-medial to the antero-lateral commissura was asymmetrical; MV tethering at the medial aspect also plays a crucial role in the genesis of IMR.¹² Based on these observations, a new remodeling annuloplasty Carpentier-McCarthy-Adams IMR ETlogix ring (CMA IMR ETlogix ring; Edwards Lifescience, Irvine, Calif) was recently developed (Figure 1). This new prosthetic ring specifically addresses the asymmetric deformation characteristic of type IIIb ischemic MR.¹³ Compared with conventional symmetric annuloplasty rings, this new design leads to increased leaflet coaptation through substantial and tailored reduction of the antero-posterior dimension in patients with IMR. The asymmetric 3-dimensional (3D) design with reduced middle to medial (P2-P3) curvature and a slight dip at the P2-P3

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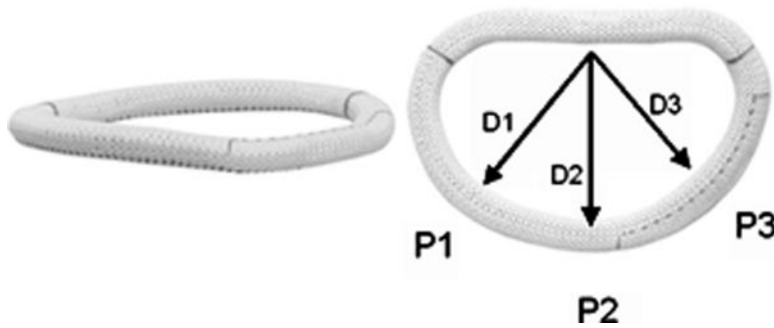


Figure 1. The new asymmetrical Carpentier-McCarthy-Adams IMR ETlogix ring (CMA IMR ETlogix ring). This new ring is undersized with a 14% reduction in the postero-medial dimension (D2, D3 dimension). Note that this ring has a slight dip at P2-P3 (left) and a narrower dimension at P2-P3 (right; D2, D3).

segments increases coaptation of the tethered P2-P3 segments.

In this study, we used quantitative 2-dimensional (2D) echocardiography to assess early operative results of MV repair with the CMA IMA ETlogix ring and to determine its impact on MV geometry in patients with IMR.

Methods

Study Population

We enrolled 59 consecutive patients (age 68 ± 12 years) who underwent MV repair with the CMA ETlogix ring for the treatment of IMR from October 2003 through August 2005 at 3 centers (Mount Sinai Hospital [31 patient], Cleveland Clinic Foundation [13 patients], and Northwestern Memorial Hospital [15 patients]). IMR was defined as significant MR (grade $\geq 2+$ MR assessed by preoperative 2D echocardiography) caused by Carpentier type IIIb or I dysfunction resulting from LV dysfunction caused by coronary artery disease. Patients with other types of mitral dysfunction (type II, excess leaflet motion; type IIIa, restricted leaflet motion in systole and diastole) or patients who had concomitant LV reconstruction were excluded.

All patients had coronary angiography preoperatively and echocardiographic studies before valve repair and 3 to 10 days after surgery (Table 1).

Echocardiographic Measurements

A team from the Cleveland Clinic Foundation (MD, SF with/without TS) traveled to each institution to review all digitalized original echo data for the purpose of consistency of echocardiographic measurements. Preoperative echocardiographic measurements were performed using images recorded 1 to 30 days before surgery (mean, 14 ± 11 days), from transthoracic echocardiography in 49 patients and from transesophageal echocardiography in 10 patients. Transthoracic echocardiography imaging recorded 3 to 10 days after surgery (mean, 5.0 ± 2.2 days) was used for all postoperative measurements. These 2D echocardiographic images were used to assess MV geometry and function, as well as LV dimensions, function, and left atrial dimension. LV end-diastolic volume (EDV) and end-systolic volume (ESV) were measured by the biplane Simpson disk method. Ejection fraction was calculated by the equation $100 \times (\text{EDV} - \text{ESV}) / \text{EDV}$. The characteristics (origin, number, and direction) of MR jets were estimated by color flow Doppler images on a parasternal long and short-axis view at the MV level and on multiple apical views. The severity of MR was graded semi-quantitatively from 0 to 4+ by color Doppler studies of the spatial distribution of the regurgitant jet¹⁴ and the size of the flow convergence/proximal isovelocity surface area from multiple imaging planes.^{14,15} For evaluating geometry of the mitral apparatus, we measured the mitral annular diameter (MAD), tethering area (TA) of the MV (defined as the area enclosed by the annular plane and 2 leaflets), and tenting height (TH) of the MV (defined as the minimal distance between the leaflet coaptation and the mitral annular plane), in 4-chamber (4ch), 2-chamber (2ch), and long-axis (LAX) views at the time of maximal MV closure in systole (Figure 2). The

transmitral velocity, measured by continuous-wave Doppler technique, was used to calculate the trans-mitral mean pressure gradient after mitral valve repair.

Surgical Procedure

Each patient underwent remodeling annuloplasty with the CMA IMR ETlogix ring.¹⁶ Intraoperative transesophageal echocardiography was used to assess LV and MV function during surgical procedure

TABLE 1. Preoperative Patient Characteristics

Characteristic	No. (%)
No. of patients	59
Gender	
Male	40 (67.8)
Female	19 (32.2)
Age	
Mean	68 ± 12
Range	35–90
Previous cardiac procedures	
Percutaneous coronary intervention	15 (25.4)
Coronary artery bypass graft	16 (27.1)
N of coronary arteries with stenosis (>50%)	
1 vessel	14 (23.7)
2 vessels	13 (22.0)
3 vessels	32 (54.2)
Rhythm	
Sinus rhythm	46 (78.0)
Atrial fibrillation	12 (20.3)
Ventricular pacing	1 (1.7)
Risk factor	
Hypertension (diastolic pressure >90 mm Hg)	32 (54.2)
Diabetes mellitus	23 (39.0)
Hyperlipidemia (cholesterol >200 mg/dL)	52 (88.1)
Smoking	18 (30.5)
Cerebrovascular accident	7 (16.9)
Renal insufficiency (creatinine ≥ 2.0 mg/dL)	11 (18.6)
Recent myocardial infarction (<14 days)	7 (11.9)
Chronic obstructive pulmonary disease	8 (13.6)
New York Heart Association Class	
I	13 (22.0)
II	23 (39.0)
III	15 (25.4)
IV	8 (13.6)

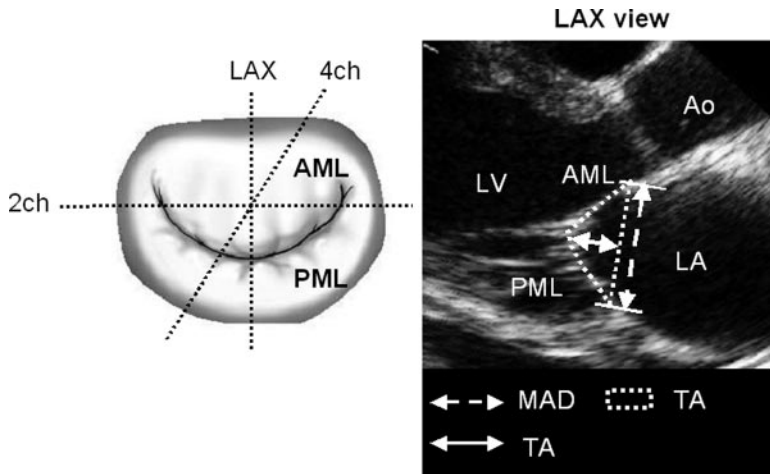


Figure 2. Schematic illustrations of 4-chamber (4ch), 2-chamber (2ch), and long-axis (LAX) views (left), and measurements of mitral annular diameter (MAD), mitral valve tethering area (TA), and mitral valve tethering height (TA) (right). AML indicates anterior mitral leaflet; PML, posterior mitral leaflet.

before and after repair. Coronary artery bypass graft, if required, was performed before MV repair. The mitral valve was approached either through the left atrium or trans-septally. Once interrupted sutures were placed around the annulus, standard Carpentier–Edwards ring sizes were used to size the valve in a typical fashion, taking into account both the anterior leaflet surface area and the inter-commissural distance. A true-sized ring was selected and the remodeling annuloplasty was completed by securing the ring to the annulus with annular sutures;¹⁶ 85% of patients received a ring of labeled size 26 or 28 mm (Table 2). A saline test was performed to confirm a reasonable line of coaptation along the margin of the leaflets.

Statistical Analysis

Data are expressed as mean±SD, frequency distribution, or simple percentage. Group comparisons of MAD, TA, and TH of MV in 3 echocardiographic views were performed by repeated-measures analysis of variance (ANOVA) followed by post hoc testing, as appropriate. Sheffe test was used for the post hoc test. The differences in other echocardiographic measurements between preoperative and postoperative values were analyzed by paired *t* test. *P*<0.05 was considered statistically significant.

Statement of Responsibility

The authors had full access to the data and take full responsibility for their integrity. All authors have read and agree to the manuscript as written.

TABLE 2. Mitral Valve Repair Procedure

	No. (%)
CMA IMR ETlogix ring size (mm)	
Mean	27.5±1.6
26	24 (40.7)
28	26 (44.1)
30	8 (13.6)
32	1 (1.7)
Concomitant procedure	
CABG	37 (62.7)
Ligation of left atrial appendage	20 (33.9)
Maze procedure	14 (23.7)
Tricuspid repair	15 (25.4)
Aortic valve replacement	7 (11.9)
PFO closure	1 (1.7)
Aortic root replacement	1 (1.7)
Transmyocardial laser revascularization	1 (1.7)

CABG indicates coronary artery bypass grafting; PFO, patent foramen ovale.

Results

LV and LA chamber and MR Severity

MR grading at baseline and after surgery are shown in Figure 3. At baseline, 13 (22.0%) patients had 2+ MR, 22 (37.3%) patients had 3+ MR, and 24 (40.7%) patients had 4+ MR. The mean MR grade and regurgitant orifice area by proximal isovelocity surface area method were 3.2±0.8 and 0.39±0.25 cm², respectively. Intraoperative post-repair echocardiography revealed that all patients had MR that was 1+ or less. Before hospital discharge, 57 patients (97%) had 0 or 1+ MR, whereas 2 patients had 2+ MR. Thus, the mean MR grade was decreased from 3.2±0.8 to 0.3±0.6 after surgery. Both patients with 2+ residual MR had infero-posterior LV wall motion abnormalities and 3+ or 4+ MR preoperatively, which was characterized by a single or 2 separate MR jets from the medial and lateral sides. Preoperative 2D echocardiography revealed LV wall motion abnormalities in the antero-septal area in 25 of 59 (42.4%) patients, the infero-posterior area in 41 of 59 (69.5%) patients, and the lateral area in 5 of 59 patients (8.5%). LV end-systolic and end-diastolic volume indices and left atrial size were significantly reduced after surgery (*P*<0.001, for all), whereas LV ejection fraction was unchanged (Figure 4). The transmitral mean pressure gradient after surgery was 3.7±1.6 mm Hg.

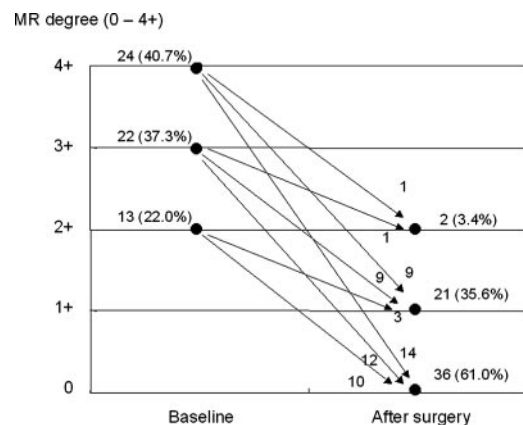


Figure 3. Change in the degree of ischemic mitral regurgitation. After surgery, 57 patients (97%) had 0 or 1+ MR, whereas 2 patients had 2+ MR.

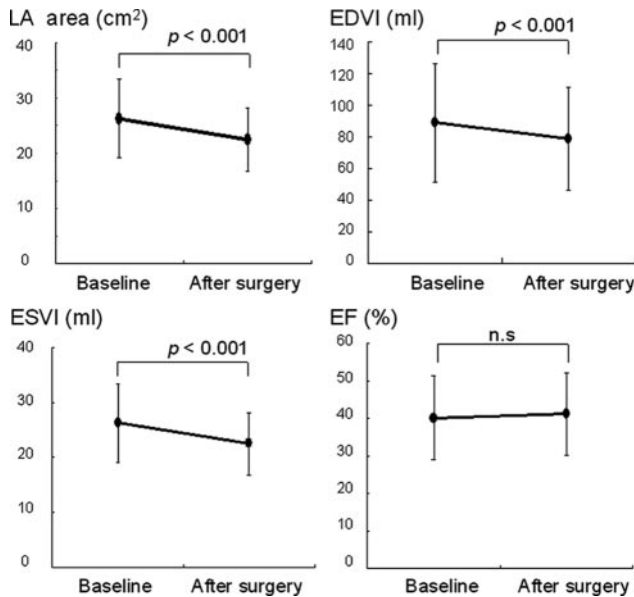


Figure 4. Changes in LV end-systolic and end-diastolic volume indices, left atrial size, and LV ejection fraction after surgery. LV end-systolic and end-diastolic volume indices and left atrial size were significantly reduced after surgery ($P < 0.001$, for all), whereas LV ejection fraction was unchanged. LA indicates left atrial; LVEDVI and LVESVI, left ventricular end-diastolic and end-systolic volume index; EF; ejection fraction.

Mitral Valvular Geometry

Changes in mitral valve geometry assessed by echo at baseline and after surgery are shown in Figure 5. At baseline, measured MAD was similar in 4ch, 2ch, and LAX views (3.0 ± 0.3 , 3.1 ± 0.3 , and 3.0 ± 0.4 cm), indicating circular deformation of the mitral annulus. In contrast, TA and TH of the MV were significantly larger in the LAX view than in 4ch

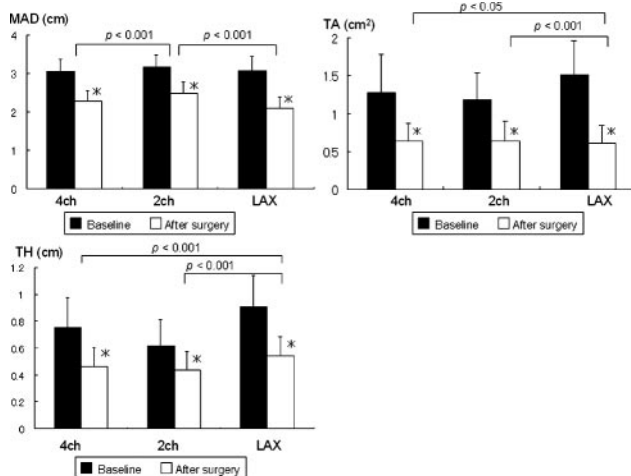


Figure 5. Comparison of MAD, and TA and TH of MV between baseline and after surgery in 4ch, 2ch, and LAX views. The significant reductions of MAD, TA, and TH were observed in all 3 echo views ($*P < 0.001$ for all). The reductions in MAD after surgery were greater in the LAX and 4ch views than in the 2ch one ($P < 0.001$ for both of LAX vs 2ch, and 4ch vs 2ch, respectively). The reductions in TA and TH after surgery were greatest in the LAX as compared with 4ch and 2ch (TA; $P < 0.05$ for LAX vs 4ch, and $P < 0.001$ for LAX vs 2ch, respectively, TH; $P < 0.001$ for both of LAX vs 4ch and LAX vs 2ch, respectively). $*P < 0.001$ vs baseline.

TABLE 3. Early Postoperative Complications

Complication	No. (%)
Atrial fibrillation (new onset)	2 (3.4)
Arrhythmia	10 (16.9)
Bleeding	3 (5.1)
Pleural effusion	13 (22.0)
Cardiac arrest	1 (1.7)
Congestive failure	17 (28.8)
Pericardial effusion	1 (1.7)
Atelectasis	1 (1.7)
Death	1 (1.7)

and 2ch views. Ten patients had TH > 11 mm, which has been suggested as a predictor of residual MR in patients with ischemic or idiopathic cardiomyopathy who have mitral valve annuloplasty.¹⁷ Mitral valve repair with the CMA IMR ETlogix ring significantly reduced MAD, TA, and TH ($P < 0.001$ for all, Figure 5). The reductions in MAD were greater in the LAX and 4ch views than in the 2ch ($P < 0.001$ for both of LAX versus 2ch, and 4ch versus 2ch), reflecting the asymmetric annuloplasty. The reductions in TA and TH were greatest in the LAX views than 4ch and 2ch (TA; $P < 0.05$ for LAX versus 4ch, and $P < 0.001$ for LAX versus 2ch, respectively, TH; $P < 0.001$ for both of LAX versus 4ch and LAX versus 2ch). Among 10 patients with TH > 11 mm,¹⁷ 1 patient had residual 2+ MR after annuloplasty.

Early Morbidity and Mortality

There was one hospital death caused by septic shock after surgery. Complications are presented in Table 3.

Discussion

This study, using quantitative 2D echocardiography, demonstrated that surgical mitral valve repair with the novel, etiology-specific CMA IMR ETlogix ring provided excellent early results with effective annular remodeling leading to a significant reduction in the antero-posterior dimension. These results were achieved by creating asymmetric changes in mitral annular diameter that effectively reduce leaflet tenting and increase leaflet coaptation.

IMR is a growing clinical problem. There is a body of evidence on the negative impact of IMR on medium-term survival in patients with coronary artery disease; the greater the degree of MR, the worse the prognosis, even in patients with mild to moderate MR.³ Recent reports document that 7 800 000 Americans experience MI annually;¹⁸ up to 19% of these patients can be expected to develop MR.^{1,2} Recent studies have suggested that coronary artery bypass graft alone does not completely correct IMR.¹⁹ Therefore, it has been suggested that patients with even mild to moderate IMR should undergo concomitant mitral valve repair at the time of myocardial revascularization.^{6,16} MV repair is now accepted to be superior to replacement in most patients,^{4,20} and undersized ring annuloplasty is commonly used to treat IMR.^{21,22} Nonetheless, MV repair with undersized flexible posterior bands or rings and even symmetric remodeling rings leaves between 10% and 30% of patients with residual or

recurrent IMR.^{4–6} This highlights the need to develop surgical strategies that target the anatomic and pathophysiological changes that contribute to the pathogenesis of IMR.^{7–12}

The initial insult in IMR is LV remodeling after myocardial ischemia or MI, which subsequently leads to posterior-medial and apical displacement of the posterior papillary muscle.^{10,11} Associated regional annular and subvalvular distortion leads ultimately to poor leaflet coaptation. Recent clinical studies have provided precise quantitative and morphological descriptions of IMR. Kwan et al¹² reported that the pattern of MV deformation from the postero-medial to the antero-lateral commissura is asymmetrical in IMR, whereas it is symmetrical in dilated cardiomyopathy. These differences in MV geometry emphasize the fact that in patients with IMR, the P2 and P3 segments are often asymmetrically restricted and associated with asymmetrical annular dilatation. Thus, treating IMR with an undersized symmetrical ring may not be the optimal approach to MV repair in IMR.⁶

With this improved pathophysiological understanding of IMR, a novel remodeling annuloplasty, the CMA IMR ETlogix ring was developed. This new prosthetic ring incorporates the principles of undersizing and specifically addresses the asymmetric deformation observed in type IIIb ischemic MR. Compared with a conventional symmetric annuloplasty, this new design leads to increased leaflet coaptation by a 3D asymmetric reduction in the antero-posterior dimension (Figure 1 right, D2 and D3 dimension) and a dip at P2-P3 segments (Figure 1 left). The new ring downsizes the medial (D3) dimension 2 sizes and the middle (D2) dimension by 1 size when compared with standard annuloplasty rings; thus, by design, this is an undersized annuloplasty. This integral feature makes it possible to select a CMA IMR ETlogix ring based on the anterior leaflet surface area measured with a standard sizer, while achieving precise remodeling with optimal coaptation in the P2-P3 region. Furthermore, this remodeling ring contains a rigid titanium core, providing complete fixation of the septal-lateral dimension during the entire cardiac cycle, which is optimal in patients with IMR.²⁰ These designs provided high early success rates (9/10, 90%) even in “high-risk patients” with TH >11 mm.¹⁷ Long-term follow-up is required to assess the durability of this result.

Study Limitations

The present study used a retrospective analysis of routine clinical echocardiographic data. Geometric changes in the mitral valve apparatus were evaluated using routine 2D echocardiography. More precise assessment by 3D echocardiography was not performed. However, we were able to quantify changes in annular geometry and leaflet coaptation in multiple 2D planes. A low incidence of residual MR after surgery and effective reductions of MAD and MV tethering were observed, indicating that the design of the CMA IMA ETlogix ring was suitable for annuloplasty in patients with IMR. Further investigations including 3D echocardiographic examination is needed to amplify understanding of geometric changes in the mitral apparatus with this technique.

We estimated MR severity semi-quantitatively by color Doppler techniques for comparison and did not quantify the

severity of IMR after surgery. However, it was relatively easy to detect significant reductions in the color jet or flow convergence to confirm the efficacy of annuloplasty. In addition, significant residual MR was not observed; therefore, quantitative methods were not necessary to assess residual MR after surgery.

Finally, this study was conducted to examine early geometric changes and operative results after annuloplasty with the CMA IMR ETlogix ring in a small number of patients. Further investigation is needed to confirm long-term effectiveness of this procedure in larger populations.

Conclusion

The present study showed that surgical repair of IMR with the novel asymmetric CMA IMR ETlogix ring provides excellent early results with geometric changes that include reductions in MAD and leaflet tethering. This novel, etiology-specific strategy may result in improved outcomes in IMR patients, including a lower incidence of residual or recurrent MR.

Source of Funding

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Disclosures

Drs Adams, Carpentier, Gillinov, and McCarthy, have served as consultants to Edwards Lifesciences, LLC. Drs Carpentier, McCarthy and Adams are inventors and receive royalties from Edwards Lifesciences, LLC.

References

- Hickey MS, Smith LR, Muhlbaier LH, Harrell FE Jr., Reves JG, Hinohara T, Califf RM, Pryor DB, Rankin JS. Current prognosis of ischemic mitral regurgitation. Implications for future management. *Circulation*. 1988;78:151–159.
- Lamas GA, Mitchell GF, Flaker GC, Smith SC Jr., Gersh BJ, Basta L, Moye L, Braunwald E, Pfeffer MA. Clinical significance of mitral regurgitation after acute myocardial infarction: Survival And Ventricular Enlargement Investigators. *Circulation*. 1997;96:827–833.
- Grigioni F, Enriquez-Sarano M, Zehr KJ, Bailey KR, Tajik AJ. Ischemic mitral regurgitation: long-term outcome and prognostic implications with quantitative Doppler assessment. *Circulation*. 2001;103:1759–1764.
- Gillinov AM, Wierup PN, Blackstone EH, Bishay ES, Cosgrove DM, White J, Lytle BW, McCarthy PM. Is repair preferable to replacement for ischemic mitral regurgitation? *J Thorac Cardiovasc Surg*. 2001;122:1125–1141.
- McGee EC, Gillinov AM, Blackstone EH, Rajeswaran J, Cohen G, Najam F, Shiota T, Sabik JF, Lytle BW, McCarthy PM, Cosgrove DM. Recurrent mitral regurgitation after annuloplasty for functional ischemic mitral regurgitation. *J Thorac Cardiovasc Surg*. 2004;128:916–924.
- Filsoufi F, Salzbeg SP, Adams DH. Current management of ischemic mitral regurgitation. *Mt Sinai J Med*. 2005;72:105–115.
- Kaul S, Spotnitz WD, Glasheen WP, Touchstone DA. Mechanism of ischemic mitral regurgitation; an experimental evaluation. *Circulation*. 1991;84:2167–2180.
- Gorman JH III, Gorman RC, Plappert T, Jackson BM, Hiramatsu Y, St John-Sutton MG, Edmunds LH Jr. Infarct size and location determine development of mitral regurgitation in the sheep model. *J Thorac Cardiovasc Surg*. 1998;115:615–622.
- Yiu SF, Enriquez-Sarano M, Tribouilloy C, Seward JB, Tajik AJ. Determinants of the degree of functional mitral regurgitation in patients with systolic left ventricular dysfunction: a quantitative clinical study. *Circulation*. 2000;102:1400–1406.
- Otsuji Y, Handschumacher MD, Liel-Cohen N, Tanabe H, Jiang L, Schwammenthal E, Guerrero JL, Nicholls LA, Vlahakes GJ, Levine RA. Mechanism of ischemic mitral regurgitation with segmental left ventricular dysfunction: three-dimensional echocardiographic studies in models

- of acute and chronic progressive regurgitation. *J Am Coll Cardiol*. 2001;37:641–648.
11. Tibayan FA, Rodriguez F, Zasio MK, Bailey L, Liang D, Daughters GT, Langer F, Ingels NB Jr., Miller DC. Geometric distortions of the mitral valvular-ventricular complex in chronic ischemic Mitral Regurgitation. *Circulation*. 2003;108(suppl II):II116–II121.
 12. Kwan J, Shiota T, Agler DA, Popovic ZB, Qin JX, Gillinov MA, Stewart WJ, Cosgrove DM, McCarthy PM, Thomas JD. Geometric differences of the mitral apparatus between ischemic and dilated cardiomyopathy with significant mitral regurgitation: real-time three-dimensional echocardiography study. *Circulation*. 2003;107:1135–1140.
 13. Carpentier A. Cardiac valve surgery—the “French correction”. *J Thorac Cardiovasc Surg*. 1983;86:323–337.
 14. Zoghbi WA, Enriquez-Sarano M, Foster E, Grayburn PA, Kraft CD, Levine RA, Nihoyannopoulos P, Otto CM, Quinones MA, Rakowski H, Stewart WJ, Waggoner A, Weissman NJ; American Society of Echocardiography. Recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and Doppler echocardiography. *J Am Soc Echocardiogr*. 2003;16:777–802.
 15. Shiota T, Jones M, Teien DE, Yamada I, Passafini A, Ge S, Sahn DJ. Dynamic change in mitral regurgitant orifice area: Comparison of color Doppler echocardiographic and electromagnetic flow meter-based methods in a chronic animal model. *J Am Coll Cardiol*. 1995;26:528–536.
 16. Aklog L, Filsoufi F, Adams DH. Ischemic Mitral Regurgitation. In: Sellke FW, Del Nido PJ, Swanson SJ, Sabiston DC, Spencer FC, eds. *Sabiston & Spencer Surgery of the Chest*, 7th ed. Philadelphia: Elsevier Saunders; 2004:1299–1344.
 17. Calafiore AM, Gallina S, Di Mauro M, Gaeta F, Iaco AL, D’Alessandro S, Mazzei V, Di Giammarco G. Mitral valve procedure in dilated cardiomyopathy: repair or replacement? *Ann Thorac Surg*. 2001;71:1146–1152.
 18. American Heart Association. Heart disease and stroke 2004 update. Dallas, TX.: American Heart Association; 2004.
 19. Aklog L, Filsoufi F, Flores KQ, Chen RH, Cohn LH, Nathan NS, Byrne JG, Adams DH. Does coronary artery bypass grafting alone correct moderate ischemic mitral regurgitation? *Circulation*. 2001;104(Suppl I):I68–I75.
 20. Miller DC. Ischemic mitral regurgitation redux—to repair or to replace? *J Thorac Cardiovasc Surg*. 2001;122:1059–1062.
 21. Adams DH, Filsoufi F, Aklog L. Surgical treatment of the ischemic mitral valve. *J Heart Valve Dis*. 2002;11(Suppl 1):S21–S25.
 22. BadwharV, Bolling SF. Mitral valve surgery in the patient with left ventricular dysfunction. *Semin Thorac Cardiovasc Surg*. 2002;14:133–136.