

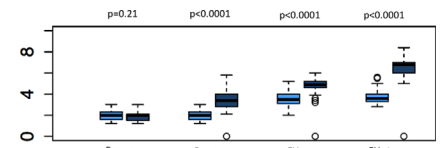
# A Comparison of 2 Mitral Annuloplasty Rings for Severe Ischemic Mitral Regurgitation: Clinical and Echocardiographic Outcomes

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Controversies regarding the choice of annuloplasty rings for treatment of ischemic mitral regurgitation still exist. Aim of the study is to compare early performance of 2 different rings in terms of rest and exercise echocardiographic parameters (transmitral gradient, systolic pulmonary artery pressure, and mitral valve area), clinical outcomes, and recurrence of mitral regurgitation. From January 2008 till December 2013, prospectively collected data of patients who underwent coronary artery bypass grafting and undersizing mitral valve annuloplasty for severe chronic ischemic mitral regurgitation at our Institution were reviewed. A total of 93 patients were identified; among them 44 had semirigid Memo 3D ring implanted (group A) whereas 49 had a rigid profile 3D ring (group B). At 6 months, recurrent ischemic mitral regurgitation, equal or more than moderate, was observed in 4 and 6 patients in the group A and B, respectively ( $P = 0.74$ ). Group A showed certain improved valve geometric parameters such as posterior leaflet angle, tenting area, and coaptation depth. Transmitral gradient was significantly higher at rest in the group B ( $P < 0.0001$ ). During exercise, significant increase of transmitral gradient and systolic pulmonary artery pressure was observed in group B ( $P < 0.0001$ ). Mitral valve area was not statistically significantly smaller at rest in between groups ( $P = 0.09$ ); however, it significantly decreased with exercise in group B ( $P = 0.01$ ). At midterm follow-up, patients in group B were more symptomatic. In patients with chronic ischemic mitral regurgitation, use of semirigid Memo 3D ring when compared to the rigid Profile 3D may be associated with early improved mitral valve geometrical conformation and hemodynamic profile, particularly during exercise. No difference was observed between both groups in recurrent mitral regurgitation.

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**Keywords:** Mitral Regurgitation (MR), Ischemic mitral regurgitation (IMR), Mitral Valve Repair (MVR), Coronary artery bypass grafting (CABG)



Changes in mean trans-mitral gradient after surgery and at 6 months follow-up.

## Central Message

The semirigid annuloplasty ring may show better early performance than a rigid saddle-shape ring in hemodynamic profile at rest and with exercise. No effect of recurrent MR was found.

## Perspective Statement

In a context of chronic ischemic mitral regurgitation, the use of a semirigid ring (memo 3D) can be associated with early improved rest and stress echocardiographic parameters and reduced NYHA class at midterm follow-up. However, it does not add benefits in reduction of recurrent mitral regurgitation when compared with a rigid ring.

See Editorial Commentary pages xx–xx.

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## INTRODUCTION

Chronic ischemic mitral regurgitation (IMR) is a secondary mitral regurgitation (MR) characterized by apparently normal leaflets and subvalvular apparatus. The mitral incompetence is the consequence of a systolic restrictive motion of the leaflets (leaflet tethering, type IIIb) or annular dilatation (type I) according to Carpentier's classification, possibly exacerbated by ventricular remodeling.<sup>1</sup> When dealing with IMR, echocardiography plays a major role in identifying the types of leaflet tethering and the change of mitral valve apparatus geometry.<sup>2</sup> Annular dimension, coaptation depth (CD), tenting area (TA) or volume, interpapillary distance, and leaflet angles are the most important echocardiographic parameters to report, representing

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predictors of recurrent MR after restrictive mitral valve annuloplasty (MVA).<sup>2</sup> To date, restrictive MVA represents the most performed techniques used to treat patients with secondary MR.<sup>3</sup> Several studies have shown that the recurrence of MR at 1-year remains high (10%-30%).<sup>4-6</sup> Moreover, it has been reported that restrictive MVA could be associated with impaired hemodynamic profile with higher transmitral gradient and systolic pulmonary artery pressure (PAP) at exercise and worsening in functional New York Heart Association (NYHA) class.<sup>7</sup> Several types of prosthetic rings exist to remodel the mitral annulus. Complete prosthetic rings are often preferred over a band because of the lower recurrent MR rate.<sup>8</sup> Complete rigid or semirigid rings have different shapes, orifice areas, and septolateral dimensions, and furthermore, they have controversial results in recurrent MR and mitral valve conformation changes.<sup>9</sup> Main aim of this study is to compare early performance of a semirigid and a saddle-shaped rigid annuloplasty rings at rest and with exercise in patients with IMR undergoing restrictive MVA associated with coronary artery bypass surgery and to assess midterm clinical status.

## MATERIALS AND METHODS

### Population

The present study is a retrospective analysis of prospectively recorded data. From January 2008 to

December 2013, patients who underwent restrictive MVA for severe chronic IMR in our institutions were reviewed. Patients fulfilling the following inclusion criteria were eligible to be included in this study: (1) history of ischemic cardiomyopathy, chronic severe IMR owing to systolic restrictive leaflet motion with or without mitral annulus dilatation, (2) sinus rhythm, (3) narrow QRS (<120 ms), and (4) absence of other mitral valve pathology. Further, 93 patients were identified; among them, 44 patients had semirigid memo 3D (Sorin) ring implanted (group A) and 49 had a rigid Profile 3D (Medtronic) ring (group B). Ethical board approved the study, and individual consent was waived. Demographics, clinical, and echocardiographic data are illustrated in Table 1.

### Operative Technique

All procedures were performed through median sternotomy on normothermic cardiopulmonary bypass with intermittent antegrade blood cardioplegia. All patients underwent coronary artery bypass grafting concomitant to restrictive MVA. Mitral annuloplasty ring size was determined by standard measurement of the intertrigonal distance and anterior leaflet surface, and then downsizing by one for the Memo 3D group was performed. For the Profile 3D group, size of ring was equal to the

**Table 1.** Baseline Clinical and Echocardiographic Characteristics

	Group A (n = 44)	Group B (n = 49)	P Value
Age (years)	64 ± 9	66 ± 8	0.09
Men (%)	79.5	61.5	0.06
NYHA 0-I (%)	47.7	49	1
NYHA II-III (%)	52.3	51	1
Infarct site			
Anterior (%)	32.8	30.3	0.15
Inferior or lateral (%)	50.5	49.5	0.13
Multiple (%)	16.7	20.2	0.16
LV EDD (mm)	56.2 ± 9	56.5 ± 7	0.12
LV ESD (mm)	47 ± 2	46 ± 1	0.21
LV EDV (mL)	117 ± 36	115 ± 28	0.15
LV ESV (mL)	62 ± 9	61 ± 12	0.17
LV ejection fraction (%)	44 ± 7	44 ± 10	0.1
SPAP (mm Hg)	36 (18.2)	32 (13)	0.004
Valve orifice area (cm <sup>2</sup> )	4 ± 0.7	4 ± 0.9	0.11
Transmitral gradient (mm Hg)	2 ± 0.5	1.9 ± 0.5	0.21
Tenting area (mm)	2.2 ± 0.4	2.1 ± 0.4	0.21
Coaptation depth (mm)	8.5 ± 1.6	8 ± 1.5	0.25
Tenting volume (mL)	7.7 ± 1.4	7.9 ± 1.4	0.09
Posterior leaflet angle (°)	33.8 ± 7.6	33.6 ± 7.8	0.12
Anterior leaflet angle (°)	21.8 ± 5.2	22.3 ± 5.3	0.16

Group A, semirigid memo 3D; group B, rigid profile 3D. Values are expressed in mean ± standard deviation or median and IQR. EDD, end-diastolic diameter; ESD, end-systolic diameter; EDV, end-diastolic volume; ESV, end-systolic volume; LV, left ventricle; NYHA, New York Heart Association; SPAP, systolic pulmonary arterial pressure.

surface of anterior leaflet. This was a single-surgeon series (K.F.).

### Echocardiographic Examination

All patients underwent preoperative and postoperative (same day of hospital discharge) transthoracic echo examinations. Intraoperative transesophageal examination was also performed routinely. All echocardiographic examinations were performed using the Philips Healthcare IE 33 echocardiograph system. All Doppler-echocardiographic recordings were stored on a dedicated workstation for off-line subsequent analysis. Measurements were performed blind of the surgical data. For each measurement, a minimum of 2 cardiac cycles was averaged. Left ventricle (LV) end-diastolic and end-systolic dimensions were measured from parasternal acquisitions. The biplane method of discs' summation (modified Simpson's rule) was applied to quantify LV end-diastolic and end-systolic volumes and ejection fraction. The severity of MR appreciated using an integrated approach. MR was quantitated using the proximal isovelocity surface area and<sup>10</sup> using the Doppler method, and the measurement of vena contracta and effective regurgitant orifice area of  $\geq 20 \text{ mm}^2$  was the threshold of severity.<sup>11</sup> Peak and mean transmitral pressure gradients were calculated using the modified Bernoulli equation. Systolic PAP was derived from the regurgitant jet of tricuspid regurgitation using systolic transtricuspid pressure gradient and with the addition of 10 mm Hg for right atrial pressure.<sup>11</sup> Septolateral annulus diameters were measured from parasternal long-axis view. CD and TA were measured from the 4-chamber view. Mitral valve area was determined by 2-dimensional planimetry. 3D echocardiographic measurements were performed using the MV Q Lab software. Results from preoperative and postoperative 2D transthoracic echocardiographic examinations were compared regarding the mitral valve geometric changes (posterior leaflet angle, TA, and CD). Heart rate and systolic blood pressure value were also recorded at rest and with exercise.

### Exercise Echocardiography

Beta-blockers were withdrawn the day of the test. A symptom-limited, graded bicycle exercise test was performed in the semisupine position on a tilting exercise table in all patients at follow-up. After an initial workload of 25 W maintained for 2 minutes, the workload was increased every 2 minutes by 25 W. Blood pressure and a 12-lead electrocardiogram were recorded every 2 min. Both the

transmitral pressure gradient and the systolic PAP were recorded.<sup>10,12</sup>

### Outcome Data

All survived patients underwent a semisupine exercise echocardiography test to assess changes in systolic PAP and transmitral pressure gradient after 6 months after the operation at our main echo laboratory. In-hospital morbidity (renal failure, respiratory distress, bleeding, mediastinitis, etc) and mortality were evaluated in all patients. The follow-up was obtained from patient interviews, hospital record reviews, or personal communications with the patient's physician. Death, NYHA functional class, and readmission for heart failure to hospital represented the collected data for midterm outcome. Cardiac-related death was defined as a sudden death or death related to myocardial infarction, congestive heart failure, or cardiac arrhythmias.

### Statistical Analysis

Patients' demographic, clinical, and operative data were summarized as mean  $\pm$  standard deviation for normally distributed continuous variables, otherwise median and interquartile range (IQR) for nonparametric continuous variables or proportion or prevalence for categorical variables was used. Differences between subgroups were compared using the  $\chi^2$  test (2-tailed) for categorical variables and the Student's *t*-test or the Mann-Whitney *U* test or Kruskal-Wallis test, as appropriate, for continuous variables. Comparisons of the data over time were performed by analysis of variance between groups. Values of *P* less than 0.05 were considered to indicate statistical significance. All statistical analyses were performed with STATISTICA version 10 (StatSoft Inc, Tulsa, Okla).

## RESULTS

### Patients' Characteristics

Patients' characteristics are listed in [Table 1](#). Mean age was  $65 \pm 10$  years and 70% were men. The site of infarction was inferior or lateral in 50%, anterior in 31.5%, and multiple myocardial necrotic sites in 18.5%. In a context of a small sample size, no statistically significant differences were found between groups regarding baseline clinical and echocardiographic variables, except for systolic PAP being significantly higher in the group A ( $P = 0.004$ ). Interestingly, mitral valve geometric parameters such as TA and volume, CD, and posterior and anterior leaflet angles, were similar in both groups ( $P = 0.21, 0.09, 0.25, 0.12, \text{ and } 0.16$ , respectively).

## Surgical Data and Postoperative Outcomes

The mean time of cardiopulmonary bypass was  $93.2 \pm 12$  minutes in the group A vs  $92.8 \pm 19$  minutes in the group B ( $P = 0.13$ ). The mean time of aortic cross-clamp was  $78 \pm 20$  minutes in the group A vs  $76 \pm 12$  minutes in the group B ( $P = 0.09$ ). The mean number of grafts was  $2.8 \pm 0.5$  for group A and  $2.8 \pm 0.9$  for group B ( $P = 0.15$ ). Hospital stay was  $9 \pm 3$  days in the group A vs  $10 \pm 6$  days in the group B ( $P = 0.16$ ). No significant differences between groups were found on postoperative complications and in-hospital deaths (Table 2). All survived patients were discharged with trivial or without MR.

## Follow-Up Data

At 6 months follow-up, rest and exercise echocardiographic examination was obtained in all patients. Recurrent  $\geq$  moderate MR was observed in 4 (9.7%) patients in the group A and 6 (13.6%) in the group B ( $P = 0.74$ ). Semirigid Memo 3D annuloplasty ring group showed superior positive reduction of CD and TA than the Profile group (Table 3). Of note, the posterior leaflet angle was significantly worsened in the rigid Profile 3D annuloplasty ring ( $36^\circ \pm 4^\circ$  group A vs  $51^\circ \pm 6^\circ$  group B,  $P < 0.0001$ ) but not the anterior leaflet angle ( $P = 0.15$ ). There were no significant differences between groups in LV diameters and LV ejection fraction (Table 3). The transmitral pressure gradient was higher at discharge and at 6 months rest echo in the group B ( $3.5 \pm 0.7$  mm Hg group A vs  $4.8 \pm 0.8$  mm Hg group B,  $P < 0.0001$ ) (Fig. 1). Systolic PAP was not statistically different at discharge but became higher at 6 months follow-up rest in group B (28 [IQR = 5] vs 34 (5) mm Hg,  $P < 0.0001$ ) (Fig. 2). The exercise-induced increase in transmitral pressure gradient ( $3.8 \pm 0.6$  mm Hg group A vs  $6.5 \pm 1.1$  mm Hg group B,  $P < 0.0001$ ), and the resulting increase in systolic PAP (26 [IQR 5] mm

Hg group A vs 40 [IQR = 10] mm Hg group B,  $P < 0.0001$ ) (Fig. 2) were also greater in the group B. The mitral valve area was smaller in group B at rest ( $2.4 \pm 0.6$  cm<sup>2</sup> vs  $2.2 \pm 0.7$  cm<sup>2</sup>,  $P = 0.09$ ) and significantly decreased with exercise ( $2.3 \pm 0.4$  cm<sup>2</sup> vs  $1.8 \pm 0.8$  cm<sup>2</sup>,  $P = 0.01$ ). Midterm telephonic follow-up was 100% complete (median = 36 months, IQR = 24, max 68 months); 2 (4.6%) and 3 (6.3%) patients died in group A and B, respectively. At midterm follow-up, 37 (90.2%) and 27 (61.3%) patients were in NYHA class 0-I and 4 (9.8%) and 17 (38.7%) in class II-III (group A and B, respectively,  $P = 0.02$ ), and the hospital readmission for congestive heart failure was significantly higher in group B (2.3% vs 8.8% group A and B, respectively  $P < 0.0001$ ) (Table 4).

## DISCUSSION

### Mitral Valve Repair and Recurrent MR

Chronic IMR remains one of the most complex and unresolved aspects of the treatment of valvular heart disease.<sup>2</sup> Restrictive MVA, which was first introduced by Bolling et al<sup>3</sup> in patients with end-stage ischemic and nonischemic dilated cardiomyopathy, has become a standard procedure for treating secondary MR. Undersized rings may reduce the leaflet area necessary to cover the orifice, move the leaflets closer, together by reducing the anteroposterior (septolateral) annular diameter, and thus facilitate effective coaptation.<sup>13-16</sup> Furthermore, restrictive annuloplasty has been associated with a high recurrence rate of MR (10%-30%), partly owing to further distortion of the mitral valve apparatus (ie, increased posterior leaflet tethering) and continuous LV remodeling.<sup>17</sup> The group of Dion et al<sup>15</sup> stressed that sufficient coaptation reserve might prevent recurrent MR, although this therapeutic approach does not directly address tethering by the remodeled LV.<sup>18,19</sup> It has been well known that recurrent MR depends not only from failure in surgical techniques

**Table 2.** Surgical Data and Postoperative Outcomes

	Group A (n = 44)	Group B (n = 49)	P Value
Number of grafts	$2.8 \pm 0.5$	$2.8 \pm 0.9$	0.15
Ring size (mm)	$28.6 \pm 1.6$	$29.1 \pm 1.7$	0.09
CPB (min)	$93.2 \pm 12$	$92.8 \pm 19$	0.13
X-clamp (min)	$78 \pm 20$	$76 \pm 12$	0.09
Hospital Stay (days)	$9 \pm 3$	$10 \pm 6$	0.16
ICU stays (days)	$1.4 \pm 0.2$	$1.2 \pm 0.8$	0.08
Complications (n/%) <sup>*</sup>	16 (36)	13 (26.5)	0.07
In-hospital death (n/%)	1 (2.2)	2 (4)	0.15

Group A, semirigid memo 3D; group B, rigid profile 3D; CPB, cardiopulmonary bypass; ICU, intensive care unit.

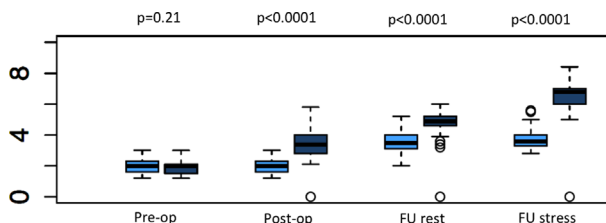
<sup>\*</sup>Mediastinitis, low cardiac output syndrome, atrial fibrillation, renal failure, respiratory failure, major bleeding. X-clamp: cross-clamp time.

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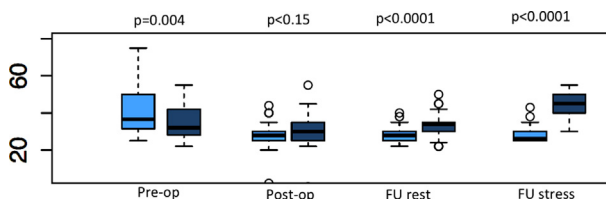
**Table 3.** Rest and Stress Echocardiographic Data Obtained at 6-Month Follow-Up

Variables	Group A (n = 43)	Group B (n = 47)	P value
<b>Rest</b>			
LV EDD (mm)	51 ± 7	53 ± 5	0.12
LV ESD (mm)	42 ± 2	43 ± 3	0.14
LV EDV (mL)	97 ± 22	110 ± 25	0.01
LV ESV (mL)	51 ± 3	58 ± 2	0.01
LV ejection fraction (%)	46 ± 5	46 ± 9	0.11
Tenting area (mm)	1.5 ± 0.3	1.8 ± 0.5	0.0004
Coaptation depth (mm)	5.3 ± 0.8	5.7 ± 0.7	0.01
Posterior leaflet angle (°)	36 ± 4	51 ± 6	<0.0001
Anterior leaflet angle (°)	20 ± 3	21 ± 3	0.15
Recurrent MR ≥ moderate (n/%)	4 (9.7)	6 (13.6)	0.74
Systolic blood pressure (mm Hg)	128 ± 7	127 ± 9	0.18
Heart rate (bpm)	70 ± 5	71 ± 7	0.16
Mitral valve area (cm <sup>2</sup> )	2.4 ± 0.6	2.2 ± 0.7	0.09
Transmitral gradient (mm Hg)	3.5 ± 0.7	4.8 ± 0.8	<0.0001
SPAP (mm Hg)	28 (5)	34 (7)	<0.0001
<b>Exercise</b>			
Systolic blood pressure (mm Hg)	170 ± 10	166 ± 14	0.12
Heart rate (bpm)	125 ± 9	129 ± 7	0.12
Mitral valve area (cm <sup>2</sup> )	2.3 ± 0.4	1.8 ± 0.8	0.01
Transmitral gradient (mm Hg)	3.8 ± 0.6	6.5 ± 1.1	< 0.0001
SPAP (mm Hg)	26 (5)	45 (10)	< 0.0001
Duration (min)	9 ± 0.5	8 ± 0.7	0.16

Group A, semirigid memo 3D; Group B, rigid profile 3D. EDD, end-diastolic diameter; ESD, end-systolic diameter; EDV, end-diastolic volume; ESV, end-systolic volume; pulmonary arterial pressure.



**Figure 1.** Changes in mean transmitral gradient after surgery and at 6 months follow-up both at rest and during exercise echocardiography. Group A memo 3D semirigid (light blue) vs Group B profile 3D rigid (dark blue). Preoperative, 2 ± 0.5 vs 1.9 ± 0.5 ( $P = 0.21$ ); postoperative (discharge) 2 ± 0.5 vs 3.4 ± 0.9 ( $P < 0.001$ ); follow-up rest (6 months) 3.5 ± 0.7 vs 4.8 ± 0.8 ( $P < 0.001$ ); follow-up stress 3.8 ± 0.6 vs 6.5 ± 1.1 ( $P < 0.001$ ). (Color version of figure is available online at <http://www.semthorcardiovascular.com>.)



**Figure 2.** Changes in pulmonary systolic artery pressure after surgery and at 6 months follow-up both at rest and during exercise echocardiography. Group A memo 3D semirigid (light blue) vs group B profile 3D rigid (dark blue). Preoperative 36(18.2) vs 32(13), ( $P = 0.004$ ); postoperative (discharge) 28 (5) vs 30(10) ( $P < 0.001$ ); follow-up rest (6 months) 28 (5) vs 34 (5) ( $P < 0.001$ ); follow-up stress 25(5) vs 45 (10) ( $P < 0.001$ ). Data are presented with median and IQR. (Color version of figure is available online at <http://www.semthorcardiovascular.com>.)

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**Table 4.** Clinical Midterm Follow-Up

Variables	Group A (n = 43)	Group B (n = 47)	P Value
Death	2 (4.6)	3 (6.3)	0.12
NYHA 0-I	37 (90.2)	27 (61.3)	0.2
NYHA II-III	6 (9.8)	20 (38.7)	0.002
Hospital readmission for CHF symptoms	2.3 ± 0.2	8.8 ± 1.6	<0.001

Group A, semirigid memo 3D; Group B, rigid profile 3D. CHF, congestive heart failure.

and patients selection but also from ongoing LV remodeling in the setting of ischemic mitral diseases. However, in our series, there were no differences in recurrent MR between the 2 groups.

## Hemodynamic Performance After Undersized Mitral Annuloplasty

It is known that the annulus restriction may reduce effective orifice areas and increase transmitral pressure gradients, resulting in functional mitral stenosis.<sup>20</sup> This is traditionally attributed to a potentially excessive reduction of mitral annular area by the ring and abnormal leaflet opening function (diastolic tethering of anterior mitral leaflet).<sup>6,7</sup> Whether the degree of mitral stenosis created by restrictive mitral annuloplasty limits patients' exercise capacity and compromises the patient outcome remains controversial.<sup>21,22</sup> However, most studies have based stenosis grading on the mean transmitral pressure gradient at rest that largely underestimates the hemodynamic effect of stenosis.<sup>23,24</sup> Exercise Doppler echocardiography may provide a comprehensive evaluation of the consequences of stenosis and of its dynamic nature as for IMR.<sup>10</sup> The more the valve opening is restricted during exercise, the higher is the increase in transmitral pressure gradient and in pulmonary pressure, and the lower is the exercise tolerance. Bertrand et al<sup>7</sup> have recently confirmed that indexed effective orifice area at peak exercise is an independent predictor of exercise capacity and clinical outcome. In our series, the transmitral pressure gradient was already higher at rest in the group B ( $3.5 \pm 0.7$  mm Hg group A vs  $4.8 \pm 0.8$  mm Hg group B,  $P < 0.0001$ ). The exercise-induced increase in transmitral pressure gradient ( $3.8 \pm 0.6$  mm Hg group A vs  $6.5 \pm 1.1$  mm Hg group B,  $P < 0.0001$ ) and the resulting increase in systolic PAP (26 (5) mm Hg vs 45 (10) mm Hg,  $P < 0.0001$ ) (Figs. 1 and 2) were also greater in the group B. Furthermore, we speculate that the high incidence of hospital readmission for congestive heart failure symptoms was observed in group B (2.3% group A vs 8.8% group B,  $P < 0.0001$ ). Moreover, we observed that mitral valve area was lower in group B with exercise ( $2.3 \pm 0.4$  mm in group A vs  $1.8 \pm 0.8$  mm in group B,  $P = 0.01$ ).

## Semirigid vs Saddle-Shaped Rigid Annuloplasty Ring

The techniques of mitral valve reconstruction have been well established, but controversies remain regarding the types of annuloplasty rings.<sup>9</sup> The available annuloplasty rings are rigid, flexible, complete, partial, or semirigid or flexible. Saddle-shaped annuloplasty rings are being increasingly used during mitral valve repair. They might provide a more favorable and uniform annular force distribution when compared to the flat rings.<sup>25,26</sup> By diminishing mitral leaflet strain and improving leaflet coaptation geometry, saddle-shaped annuloplasty may thus enhance repair durability. Therefore, the mitral valve reconstruction primarily aims at restoring not only a normal valve anatomy but also a normal valve function.<sup>1</sup>

The design and structure of annuloplasty rings are constantly evolving. The semirigid Memo 3D annuloplasty ring is capable of mimicking the physiological 3D motion of the native mitral annulus and accommodating the anatomical shape while remodeling the mitral annulus and ensuring the leaflet coaptation during systole. The rigid Profile 3D annuloplasty ring has a unique design based on the saddle-shaped geometry of normal human mitral annuli. Although the general goal of these devices is the same, namely, to increase leaflet coaptation and to support the posterior annulus against dilation, the extent of change in mitral valve configuration is not uniform. For instance, the septolateral distance is shorter in the rigid Profile 3D annuloplasty ring than in the semirigid Memo 3D annuloplasty ring (ie, for 28 mm size ring the septolateral distance is 15.6 mm and 17.8 mm, respectively, for Memo 3D and Profile 3D; data by manufacturing company), and the orifice area is smallest. In our study, we confirmed that the magnitude and direction of improvement in mitral valve geometric parameters was considerably different between groups. With the semirigid Memo 3D annuloplasty ring, except for the anterior leaflet angle, all the parameters improved. Conversely, with the rigid Profile 3D annuloplasty ring, the posterior leaflet angle worsened after the implantation probably because of the smallest septolateral distance with respect to Memo 3D ring (increased posterior leaflet tethering). Moreover, the CD and TA

are smaller in Memo 3D vs 3D profile ring. Therefore, we can speculate that these observations are because of the fact that the Memo 3D ring can mimic the native motion of the mitral annulus specifically in end-systole and improve the coaptation between the leaflets. However, in this series, restrictive annuloplasty proved to be effective regardless of the ring used, as there was no significant difference in recurrent MR between the 2 groups.

Previous studies have highlighted the potential risk of functional mitral stenosis after restrictive annuloplasty with the Carpentier-Edwards Physio ring (Edwards Lifesciences Corporation), but not with the asymmetric IMR ETlogix ring (Edwards Lifesciences Corporation).<sup>27</sup> The different geometric and functional characteristics of the IMR ETlogix ring have been largely incriminated in these differences. Whether semirigid rings provide more reliable functional repair results than saddle-shaped rigid rings have not been evaluated. In our study, the semirigid Memo 3D annuloplasty ring was associated with a better hemodynamics (lower transmitral pressure gradient and systolic PAP) at rest and during exercise and clinical status (lower NYHA functional class). Moreover, the mitral valve area was larger rather than in rigid Profile 3D annuloplasty ring. The hemodynamic benefit of the semirigid Memo 3D annuloplasty ring has been recently outlined.<sup>28</sup> Conversely, the rate of exercise-induced increase in transmitral pressure gradient and the resulting rise in systolic PAP was significantly higher with the rigid Profile 3D annuloplasty ring. These data suggest that the semirigid Memo 3D annuloplasty ring has less potential risk of postoperative functional stenosis. This could possibly be related to a structural advantage of this ring that is capable to mimicking the normal motion of the annulus, which preserves both the anteroposterior movement and folding dynamics.<sup>29</sup> However, we believe that the improvement in tenting parameters observed in Memo 3D group is not necessary attributed to the use of ring in itself but also depend on LV reverse remodeling and subsequent geometric mitral apparatus modifications.

## LIMITATIONS

We can identify several limitations of our study. First, this was a single-center study with limited

sample size. The complexity of the disease and the potential heterogeneity of the patients enrolled might have introduced some bias. This might explain some subtle differences between the 2 study groups at study baseline. However, our population represented the patients seen in our Heart Valve Clinic. The right atrial pressure was estimated at 10 mm Hg both at rest and during exercise. Resting right atrial pressure is extensively variable between subjects. In addition, this estimation may also miss the potential influence of exercise-induced changes in right atrial pressure. Nevertheless, the noninvasive evaluation of right atrial pressure during exercise (ie, when venous compliance is known to decrease) with noninvasive methods such as Doppler echocardiography remains difficult, is probably subject to low accuracy, and is not validated. Moreover, right atrial pressure is frequently assumed to be 5 mm Hg in normal subjects<sup>30</sup> and 10 mm Hg in patients with heart disease.<sup>31</sup> Though we have demonstrated higher risk of functional mitral stenosis in patients receiving a Profile rigid ring, this cannot be generalized to all category or rigid rings; moreover, we cannot say whether or not this actually results in a poorer clinical outcomes or survival rate in the long run. Long-term follow-up data and more investigations are needed to address this issue.

## CONCLUSION

Undersized MVA is still the most popular technique used to treat IMR despite that recurrent MR is still high and functional mitral stenosis should occur. In our study, the semirigid Memo 3D annuloplasty ring was associated with enhanced hemodynamic performance at rest and during exercise, which was translated by a reduced risk of postoperative functional stenosis and a better clinical functional status. Despite the improvement in tenting parameters in the semirigid group, no difference was observed between the 2 groups for MR recurrence. Up till now, no data may suggest that semirigid rings could be preferred to rigid one for treating IMR. For a future perspective in valve-in-ring implantation, the use of semirigid ring would be preferred. However, continuous investigations are mandatory to clarify these findings.

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