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Mitral Valve Annuloplasty: The Effect of the Type on Left Ventricular Function

Tirone E. David, MD, Masashi Komeda, MD, Charles Pollick, MD, and Robert J. Burns, MD

Divisions of Cardiovascular Surgery and Cardiology, Toronto Western Hospital and University of Toronto, Toronto, Ontario, Canada

This study was undertaken to determine whether rigid-ring annuloplasty and flexible-ring annuloplasty have the same effect on left ventricular function in patients with chronic mitral regurgitation secondary to degenerative disease of the mitral valve. Twenty-five patients who underwent isolated mitral valve repair and required annuloplasty were randomized into two groups: rigid-ring and flexible-ring annuloplasty. Left ventricular function was assessed by echocardiography and radionuclide angiography on the day before operation and 2 to 3 months later. Preoperative left ventricular function was similar in the two groups of patients. Postoperatively, left ventricular end-diastolic diameter and volume decreased significantly in both groups. The left ventricular end-systolic diameter and volume decreased significantly only in patients with a flexible annuloplasty ring. Left ventricular systolic function as assessed by pressure–volume relationships was significantly better in patients with a flexible ring ($p < 0.02$ by analysis of covariance), and left ventricular performance measured by stroke volume–end-diastolic volume relationships was also better in these patients ($p < 0.05$ by analysis of covariance). These data indicate that patients with a flexible annuloplasty ring have better left ventricular systolic function than patients with a rigid annuloplasty ring 2 to 3 months after mitral valve reconstruction for chronic mitral regurgitation secondary to degenerative disease of the mitral valve.

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There is mounting evidence in the surgical literature that the mitral valve is an integral part of the left ventricle and that its anatomical presence plays an essential role in left ventricular geometry and mechanics [1–5]. The mitral annulus has a sphincterlike function, which reduces its area by approximately 26% during systole [6]. The mitral annulus is quite circular during diastole but becomes more elliptical in systole [6]. This change in size and shape is thought to be secondary to the relaxation and contraction of the basoconstrictor muscles (bulbospiral and sinospiral muscle bundles) [7]. Experimental fixation of the mitral annulus with a rigid prosthesis such as an artificial mitral valve or a rigid annuloplasty ring impairs left ventricular systolic function [2]. This study was undertaken to observe the effect of rigid and flexible annuloplasty rings on left ventricular function in patients who had mitral valve repair for chronic mitral regurgitation.

Material and Methods

Twenty-seven patients who underwent mitral valve repair because of chronic mitral regurgitation secondary to myxomatous disease were randomized into two groups: one treated with rigid annuloplasty (Carpentier's ring) and the other, with flexible annuloplasty (Duran's ring). The randomization was done in the operating room after the mitral valve was repaired and mitral annuloplasty was deemed necessary because of gross dilation of the annulus. Two patients were excluded from the study; 1 patient had substitution of a rigid ring by a flexible ring because of left ventricular outflow tract obstruction, and the other had postoperative evidence of mild mitral regurgitation by Doppler echocardiography. The remaining 25 patients underwent either rigid-ring (11 patients) or flexible-ring annuloplasty (14 patients).

All patients had chronic mitral regurgitation secondary to degenerative disease of the mitral valve. There were 18 men and 7 women whose mean age was 59 years (range, 41 to 76 years). Only 1 patient in each group was in atrial fibrillation before operation. The clinical presentation and functional class were similar in both groups. One patient from the rigid ring group and 2 patients from the flexible ring group were in New York Heart Association Functional class II, 8 and 9 patients, respectively, were in class III, and 2 and 3 patients, respectively, were in class IV.

All patients were studied by Doppler echocardiography and radionuclide angiography on the day before operation and 2 to 3 months later. Postoperative radionuclide angiograms were obtained at rest and during exercise. The radionuclide angiograms were performed with simultaneous recording of phonocardiogram, carotid artery pulse, and cuff blood pressure [8]. These measurements were made to allow us to determine systolic pressure–volume relationships and stroke volume–end-diastolic volume relationships [9]. All patients were on a regimen of Coumadin (crystalline warfarin sodium) during the first 3 postoperative months.

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Address reprint requests to Dr David, Toronto Western Hospital, 399 Bathurst St, Toronto, Ont, Canada M5T 2S8.

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Table 1. Operative Data[a]

Variable	Rigid Ring	Flexible Ring
Valve pathology		
Flail posterior leaflet	8	10
Flail anterior leaflet	2	1
Flail anterior and posterior leaflets	1	3
Valve repair		
Resection of part of posterior leaflet	8	10
Resection of posterior leaflet + shortening of chordae tendineae of anterior leaflet	1	3
Replacement of chordae tendineae with Gore-Tex sutures	2	1
Ring size (mm)	31.6 ± 1.9	32 ± 1.6
Aortic cross-clamping (min)	44 ± 9	40 ± 11
Cardiopulmonary bypass (min)	59 ± 14	54 ± 8

[a] Where applicable, data are shown as the mean ± the standard deviation.

The preoperative and postoperative changes in ventricular dimensions, volumes, blood pressure, and heart rate were analyzed by Student's t tests. The two groups of patients were compared by independent t tests and by analysis of variance when indicated. Postoperative left ventricular systolic function (pressure–volume relationships) and left ventricular performance (stroke volume–end-diastolic volume relationships) of the two groups were compared by analysis of covariance.

Results

There were no operative deaths among the 25 patients. Table 1 summarizes the operative data. Two patients in the flexible-ring group experienced serious postoperative complications. One elderly woman with chronic obstructive lung disease required 2 weeks of ventilatory support, and 1 man required reoperation in the third postoperative week because of paravalvular mitral regurgitation secondary to dehiscence of the posterior part of the mitral annulus, which had been plicated after resection of a portion of the posterior leaflet. There were no perioperative myocardial infarctions and no cases of low cardiac output syndrome.

At the end of the second postoperative month, all but 3 patients were functionally in New York Heart Association class I. Two patients from the flexible-ring group and 1 from the rigid-ring group were functionally in class II.

No patient had postoperative clinical or echocardiographic evidence of mitral regurgitation. In addition, no patient had echocardiographic evidence of left ventricular outflow tract obstruction. Table 2 shows the preoperative and postoperative echocardiographic data. Preoperative systolic and diastolic left ventricular dimensions were similar in both groups. Postoperatively, the decrease in left ventricular end-diastolic diameter was significant in both groups. The decrease in end-systolic diameter, however, was significant only in patients with flexible-ring annuloplasty ($p < 0.03$). The postoperative mitral valve orifice measured 3.41 ± 1.51 cm^2 in patients with a rigid ring and 2.93 ± 0.57 cm^2 in patients with a flexible ring (p = not significant).

Table 3 shows the radionuclide angiographic data. The preoperative left ventricular volume, ejection fraction, systolic blood pressure, and heart rate were similar in both groups of patients. Postoperatively, the end-diastolic volume index decreased significantly in both groups ($p < 0.001$), but the end-systolic volume index decreased significantly only in patients with a flexible ring ($p < 0.02$).

Postoperatively, the rise in heart rate and systolic blood pressure during maximum exercise was significant in both groups ($p < 0.001$). The rise in blood pressure in patients with a flexible ring was greater than in patients with a rigid ring. The end-systolic volume index during exercise increased slightly in patients with a rigid ring, but the difference did not reach significance. The left ventricular ejection fraction increased in both groups during exercise.

Left ventricular systolic function as measured by pressure–volume relationships (Fig 1) was distinctly better in patients with a flexible ring ($p < 0.02$ by analysis of covariance). Left ventricular performance was also superior in patients with a flexible ring ($p < 0.05$) (Fig 2).

Comment

The interactions between the mitral valve and the left ventricle are complex and not yet entirely understood. Experimental studies have conclusively demonstrated that the mitral valve plays an important role in left ventricular geometry and function [1–5]. The continuity between the mitral annulus and the ventricular wall through the chordae tendineae and papillary muscles is probably the most important factor in the valvular–ventricular interactions [1–5].

Table 2. Preoperative and Postoperative Echocardiographic Data[a]

Measurement	Rigid Ring	Flexible Ring
EDDI (mm)		
Preop	32.5 ± 4.3	32.8 ± 4.6
Postop	27.0 ± 2.9[b]	26.7 ± 3.4[b]
ESDI (mm)		
Preop	21.0 ± 6.0	21.4 ± 2.9
Postop	20.1 ± 4.4	18.4 ± 2.4[b]
Fraction shortening (%)		
Preop	33 ± 10	33 ± 9
Postop	26 ± 13	30 ± 9
Body surface area (m^2)	1.81 ± 0.23	1.83 ± 0.19
Mitral valve area postop (cm^2)	3.47 ± 1.5	2.93 ± 0.57

[a] Data are shown as the mean ± the standard deviation. [b] This represents a significant change from the preoperative value.

EDDI = end-diastolic diameter index; ESDI = end-systolic diameter index.

Table 3. Radionuclide Angiographic Data[a]

Variable	Rigid Ring	Flexible Ring
EDVI (mL/m^2)		
1	152 ± 49	159 ± 27
2	93 ± 26[b]	98 ± 19[b]
3	111 ± 49[c]	116 ± 20[c]
ESVI (mL/m^2)		
1	56 ± 28	59 ± 18
2	48 ± 24	41 ± 13[b]
3	52 ± 31	42 ± 14
EF (%)		
1	64 ± 12	63 ± 7
2	51 ± 12[b]	57 ± 13[b]
3	55 ± 12[c]	63 ± 11[c]
SBP (mm Hg)		
1	124 ± 10	125 ± 12
2	130 ± 15	140 ± 13
3	165 ± 16[c]	192 ± 25[c]
HR (beats/min)		
1	82 ± 10	80 ± 16
2	85 ± 4	80 ± 13
3	125 ± 11[c]	126 ± 26[c]
Maximum KPM		
3	654 ± 157	714 ± 129

[a] Data are shown as the mean ± the standard deviation. [b] This represents a significant change from the preoperative value. [c] This represents a significant change from the postoperative resting value.

EDVI = end-diastolic volume index; EF = ejection fraction; ESVI = end-systolic volume index; HR = heart rate; KPM = kilo · pond · meter; SBP = systolic blood pressure; 1 = preoperative values; 2 = postoperative values at rest; 3 = postoperative values at maximum exercise.

The mitral annulus changes its size and shape during the cardiac cycle [6]. Fixation of the mitral annulus with a rigid prosthesis such as an artificial mitral valve can adversely affect left ventricular function. This question was addressed more than 20 years ago by Tsakiris and associates [10], whose experimental work suggested that rigid fixation of the mitral annulus did not have a harmful effect on the left ventricle. We [2] compared the effect of rigid versus flexible mitral rings in isolated porcine hearts and could not corroborate those findings. Rather, we found that fixation of the mitral annulus with a rigid prosthesis was detrimental to systolic function of the left ventricle of pigs.

Patients with chronic mitral regurgitation secondary to myxomatous changes of the mitral valve have a dilated but contractile mitral annulus. These patients often need an annuloplasty as part of the reconstructive procedure to correct the mitral regurgitation. The annuloplasty serves to decrease the area that the leaflets have to seal, and it also allows the leaflets to coapt along several millimeters from their free margins, thus decreasing the probability of tears in areas where segments of leaflets were resected and chordae were shortened or replaced.

A number of different types of mitral annuloplasty have

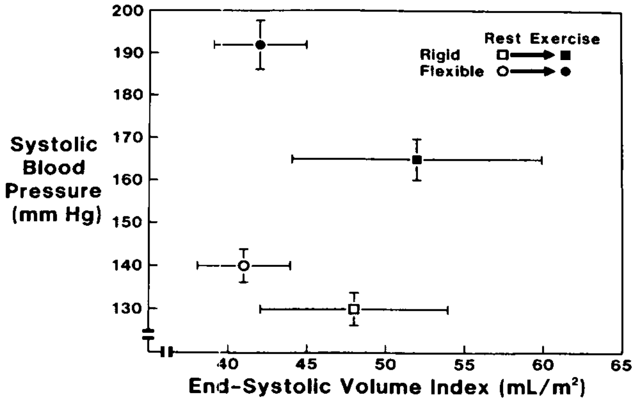

Fig 1. Left ventricular systolic function at rest and during maximum exercise as measured by pressure–volume relationships.

been employed over the years. Annuloplasty with a ring as described by Carpentier and associates [11] and, more recently, by Duran and Ubago [12], is probably the most dependable and durable of all types of annuloplasty. The Carpentier ring is rigid and remodels the mitral annulus to the size and shape of the ring [13]. The Duran ring is flexible and simply reduces the annulus to the size of the ring, allowing changes in shape during the cardiac cycle [12].

The clinical observations presented here corroborate the experimental findings that fixation of the mitral annulus with a rigid ring is more detrimental to systolic left ventricular function than fixation with a flexible ring [2]. Preoperative and postoperative mitral valve function was assessed by Doppler echocardiography, and left ventricular function was assessed by echocardiography and radionuclide angiography. The left ventricular end-diastolic dimensions and volumes decreased in both groups of patients after operation. This is usually observed in patients who have surgical correction of chronic mitral regurgitation by valve repair or valve replacement [14–16]. The end-systolic dimensions and volumes did not decrease significantly in patients with a rigid annuloplasty ring, but did so in patients with a flexible ring (see Tables

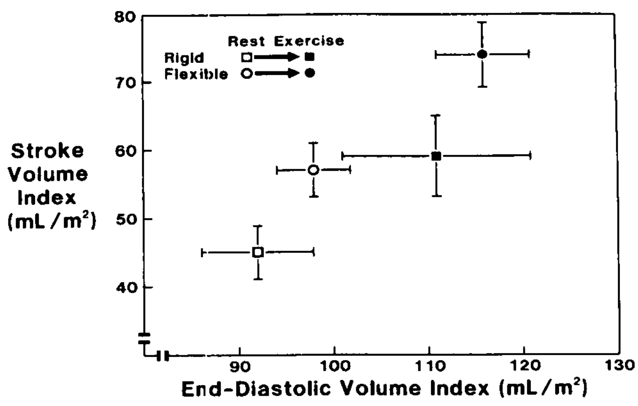

Fig 2. Left ventricular performance at rest and during maximum exercise as measured by stroke volume–end-diastolic volume relationships.

2, 3). This may be due to the fact that rigid fixation of the mitral annulus can impair the stretching and shortening of the proximal part of the basoconstrictor muscles. A very important finding was that systolic pressure–volume relationships of the left ventricle during exercise were significantly better in patients with a flexible annuloplasty ring (see Fig 1). Left ventricular performance was also better in these patients (see Fig 2).

We chose to study patients with chronic mitral regurgitation secondary to degenerative mitral valve disease because they usually have a contractile mitral annulus. We might not have shown any difference between rigid and flexible annuloplasty rings had we studied patients with rheumatic mitral regurgitation. The mitral annulus is already fairly rigid in patients with rheumatic mitral regurgitation, and fixation with a rigid or flexible ring might not seriously affect left ventricular function. The sudden alteration in the mitral annulus from a fairly contractile state to a rigid state might have an adverse effect on left ventricular function. This is perhaps the reason why fixation of the mitral annulus depresses left ventricular function in experimental animals and in patients with a normally contracting mitral annulus.

It has been documented that with time, there is an improved response of left ventricular function to mitral valve replacement [14]. We recently speculated that this might also be the case with mitral valve repair and that the results observed in this study might have been different if our postoperative hemodynamic assessments had been done longer than 2 to 3 months after operation. At the time of preparation of this report, 6 of the 25 randomized patients had a second hemodynamic assessment at 1 year postoperatively. All 6 patients demonstrated a dramatic improvement in left ventricular dimensions, volumes, and systolic function regardless of the type of annuloplasty ring used. The postoperative left ventricular function was practically normal in these 6 patients at 1 year after operation. This number of patients is too small to draw conclusions, but these results suggest that left ventricular function after mitral valve repair continues to improve beyond the second and third postoperative months and that the left ventricle may have compensatory mechanisms to overcome the problem of a rigid or flexible mitral ring as long as the mitral valve remains part of the left ventricle.

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DISCUSSION

DR DELOS M. COSGROVE (Cleveland, OH): I'd like to congratulate the authors on another important contribution to our understanding of the interaction of the left ventricle and the mitral valve on ventricular function. It was Dr David who initially renewed our interest in the contribution of the subvalvular mechanism to left ventricular function with his clinical and experimental observations. This paper adds substantially to this body of information by pointing out the importance of a flexible annulus for preservation of ventricular contractility.

While the manuscript documents the initial superior left ventricular function with the use of a flexible ring, it also alludes to two other problems associated with the use of annuloplasty rings. A smaller orifice area was calculated for patients with a flexible ring, although this did not achieve clinical or statistical significance in this particular study. This smaller valve orifice area probably results from plication of the entire annulus, including the anterior portion of the mitral annulus.

Second, Dr David had 1 case of systolic anterior motion of the anterior leaflet of the mitral valve causing left ventricular outflow tract obstruction. This has occurred in 8% of our patients with degenerative mitral valve disease who had a rigid annuloplasty ring placed as part of their valvuloplasty. This may be in part secondary to the rigid ring forcing the annulus into a euclidian plane as opposed to allowing it to assume its normal saddle-shape.

When valvuloplasty is performed, an annuloplasty ring is placed for four reasons: to correct the dilation of the annulus of the posterior portion of the leaflet, to increase leaflet coaptation, to reinforce the annular sutures, and to prevent future annular dilation.

To accomplish these functions and preserve maximum valve orifice area and ventricular function, the ideal annuloplasty ring should be universally flexible and provide a measured plication of the annulus of the posterior leaflet only. Currently, there is no annuloplasty ring that meets these requirements without compromising cardiac function.

I'd like to ask Dr David if he would speculate not only on the short-term aspect of ventricular function but on the influence of the type of annuloplasty ring on long-term ventricular function.

DR HENRY M. SPOTNITZ (New York, NY): This paper expands our understanding of the pathophysiology of surgical correction of mitral regurgitation, a clinical challenge characterized over the years by high mortality and low postoperative ejection fraction.

Laboratory investigators have identified four possible causes of adverse effects of mitral regurgitation operations on left ventricular function. The first is decreased total stroke volume through elimination of the low resistance pathway to the left atrium. The second is disruption of the papillary muscle apparatus. The third is stiffening of the normally flexible mitral annulus with a rigid prosthesis. The fourth is possible increased myocardial vulnerability, resulting in inadequate myocardial protection with standard techniques.

Clinical studies are consistent with these laboratory observations. Dr Calvin Wong and I confirmed the role of the low resistance blowoff in 1979. Dr David and his colleagues demonstrated the importance of preservation of the papillary muscle apparatus in a prior study. In the present study, they appear to have confirmed the importance of the flexible annulus. Many clinical studies, including those from our own laboratory, suggest enhanced importance of myocardial protection in these patients.

I have several questions for the authors. In connection with the issue of myocardial protection, were intraoperative studies of contractility or ejection fraction performed? Were late follow-up studies performed that might indicate continuing decrease in heart size? If so, what might be the source of restoring forces needed to decrease end-diastolic volume?

I congratulate the authors on the ongoing excellence of their clinical and physiological observations.

DR ZOHAIR AL-HALEES (Riyadh, Saudi Arabia): I congratulate Dr David for his elegant study. Let me add another advantage to the Duran ring, which at this time is a surgical advantage. This is a maneuver described by Dr Duran himself, who is currently with us at the King Faisal Specialist Hospital in Riyadh, Saudi Arabia.

We perform the ring annuloplasty but do not tie down the sutures. Instead, we bring the ring down and hold it with three tourniquets and check for competence. If the repair is satisfactory, we tie the sutures. If the repair is totally unsatisfactory, then we remove the valve and replace it. Up until this point you can do the same with a Carpentier ring, but if you discover a problem with the subvalvular apparatus, then there is an advantage for the Duran ring.

At this stage you can split the ring in half and bring it up away from the valve, and that would make the exposure very good, allowing easy access for performing the subvalvular repair. We have found this maneuver very helpful, and it can be utilized whenever there is doubt about the repair to save time.

Another advantage for the flexible annuloplasty ring is that you can still perform commissuroplasty even while the ring is in place.

A question that one might think about is whether the ring remains flexible after implantation. A ring explanted 5 years after implantation remained flexible, which proves the fact.

It is important to point out the changes in the shape of the mitral valve in systole and diastole with both Carpentier and Duran rings in place. With the Carpentier ring, the shape of the valve remains rigid and unchanged between systole and diastole, whereas with the flexible Duran annuloplasty ring, the valve can take the shape of the normal mitral valve in systole.

These advantages and what Dr David discussed in his paper make us firmly believe in the excellent results achieved in mitral valve repair utilizing the flexible Duran ring.

DR DAVID: I would like to thank Drs Cosgrove, Spotnitz, and Al-Halees for their comments. I will try to answer their questions.

I do not have a good explanation why the postoperative Doppler studies showed a slightly larger mitral orifice in patients with a rigid annuloplasty ring. I should emphasize that the difference did not reach significance. Although pursestring suture of the mitral annulus is possible during the insertion of a Duran ring, I do not believe this is the explanation in our cases. We secure this type of ring with a running suture that is passed through the mitral annulus and around the ring. We found that this technique minimizes the possibility of this complication. We secure the Carpentier ring with interrupted sutures.

There is indeed a temporal response of the left ventricular function after mitral valve reconstruction. The results presented in this study are those we obtained 2 to 3 months after operation. A small number of patients had their ventricular function reassessed at 1 year after operation and they were amazingly normal, regardless of the type of ring. I am committed to continue investigating this phenomenon and shall report the results to you in the future.

I have to admit that I am somewhat casual with myocardial protection during short operations. Mitral valve reconstruction can usually be done within 35 to 40 minutes and I use a little more than 1 L of cold blood cardioplegia in one or two shots and systemic hypothermia of 30°C. None of the patients in this study had electrocardiographic or enzymatic evidence of myocardial infarction.