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Ann Thorac Surg 1989;47:524-528
DOI: 10.1016/0003-4975(89)90426-8

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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

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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.


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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0003-4975/89/53.50
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 $3.41 \pm 1.51 \text{ cm}^2$ in patients with a rigid ring and $2.93 \pm 0.57 \text{ cm}^2$ 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 1. Operative Dataa

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

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

### Table 2. Preoperative and Postoperative Echocardiographic Dataa

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Rigid Ring</th>
<th>Flexible Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDDI (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preop</td>
<td>32.5 ± 4.3</td>
<td>32.8 ± 4.6</td>
</tr>
<tr>
<td>Postop</td>
<td>27.0 ± 2.9a</td>
<td>26.7 ± 3.4a</td>
</tr>
<tr>
<td>ESDI (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preop</td>
<td>21.0 ± 6.0</td>
<td>21.4 ± 2.9</td>
</tr>
<tr>
<td>Postop</td>
<td>20.1 ± 4.4</td>
<td>18.4 ± 2.4a</td>
</tr>
<tr>
<td>Fraction shortening (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preop</td>
<td>33 ± 10</td>
<td>33 ± 9</td>
</tr>
<tr>
<td>Postop</td>
<td>26 ± 13</td>
<td>30 ± 9</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.81 ± 0.23</td>
<td>1.83 ± 0.19</td>
</tr>
<tr>
<td>Mitral valve area postop (cm²)</td>
<td>3.47 ± 1.5</td>
<td>2.93 ± 0.57</td>
</tr>
</tbody>
</table>

a Data are shown as the mean ± the standard deviation.  
a This represents a significant change from the preoperative value.  
EDDI = end-diastolic diameter index; ESDI = end-systolic diameter index.
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 found that fixation of the mitral annulus with a rigid prosthesis such as an artificial mitral valve 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 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

**Table 3. Radionuclide Angiographic Data**

<table>
<thead>
<tr>
<th>Variable Rigid Ring</th>
<th>Flexible Ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>EDVI (mL/m²)</td>
<td>Rigid Ring</td>
</tr>
<tr>
<td>1 152 ± 49</td>
<td>195 ± 27</td>
</tr>
<tr>
<td>2 93 ± 26b</td>
<td>98 ± 19b</td>
</tr>
<tr>
<td>3 111 ± 49b</td>
<td>116 ± 20b</td>
</tr>
<tr>
<td>ESVI (mL/m²)</td>
<td></td>
</tr>
<tr>
<td>1 56 ± 28</td>
<td>59 ± 18</td>
</tr>
<tr>
<td>2 48 ± 24</td>
<td>41 ± 13b</td>
</tr>
<tr>
<td>3 52 ± 31</td>
<td>42 ± 14</td>
</tr>
<tr>
<td>EF (%)</td>
<td></td>
</tr>
<tr>
<td>1 64 ± 12</td>
<td>63 ± 7</td>
</tr>
<tr>
<td>2 51 ± 12b</td>
<td>57 ± 13b</td>
</tr>
<tr>
<td>3 55 ± 12c</td>
<td>63 ± 11c</td>
</tr>
<tr>
<td>SBP (mm Hg)</td>
<td></td>
</tr>
<tr>
<td>1 124 ± 10</td>
<td>125 ± 12</td>
</tr>
<tr>
<td>2 130 ± 15</td>
<td>140 ± 13</td>
</tr>
<tr>
<td>3 165 ± 16c</td>
<td>192 ± 25c</td>
</tr>
<tr>
<td>HR (beats/min)</td>
<td></td>
</tr>
<tr>
<td>1 82 ± 10</td>
<td>80 ± 16</td>
</tr>
<tr>
<td>2 85 ± 4</td>
<td>80 ± 13</td>
</tr>
<tr>
<td>3 125 ± 11c</td>
<td>126 ± 26c</td>
</tr>
<tr>
<td>Maximum KPM</td>
<td></td>
</tr>
<tr>
<td>3 654 ± 157</td>
<td>714 ± 129</td>
</tr>
</tbody>
</table>

*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.

---

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

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

This study was supported by a grant from the Ontario Heart and Stroke Foundation of Ontario.

We thank Dr. R. D. Weisel for assisting us with the statistical analyses and Dr. A. Kerwin, J. David, and S. Muir for helping to prepare the manuscript.

References

tricular 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, includ-
ing 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 com-
promising 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 ventric-
ular 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 vulnera-
bility, resulting in inadequate myocardial protection with stan-
dard techniques.

Clinical studies are consistent with these laboratory observa-
tions. Dr Calvin Wong and I confirmed the role of the low
resistance blowoff in 1979. Dr David and his colleagues dem-
onstrated 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 satisfac-
tory, 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 pursuring struc-
ture 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 reass-
sessed 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.
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