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Changes in Mitral Valve Annular Geometry After Repair: Saddle-Shaped Versus Flat Annuloplasty Rings

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Abstract

Background—Saddle-shaped annuloplasty rings are being increasingly used during mitral valve (MV) repair to conform the mitral annulus to a more nonplanar shape and possibly reduce leaflet stress. In this study utilizing three-dimensional transesophageal echocardiography we compared the effects of rigid flat rings with those of the saddle rings on the mitral annular geometry. Specifically we measured the changes in nonplanarity angle (NPA) before and after MV repair.

Methods—Geometric analysis on 38 patients undergoing MV repair for myxomatous and ischemic mitral regurgitation with full flat rings (n = 18) and saddle rings (n = 18) were performed. The acquired three-dimensional volumetric data were analyzed utilizing the “Image Arena” software (TomTec GmbH, Munich, Germany). Specifically, the degree of change in the NPA was calculated and compared before and after repair for both types of rings.

Results—Both types of annuloplasty rings resulted in significant changes in the geometric structure of the MV after repair. However, saddle rings lead to a decrease in the NPA (7% for ischemic and 8% for myxomatous MV repairs) (ie, made the annulus more nonplanar), whereas flat rings increased the NPA (7.9% for ischemic and 11.8% for myxomatous MV repairs) (ie, made the annulus less nonplanar); *p* value 0.001 or less.

Conclusions—Implantation of saddle-shaped rings during MV repair surgery is associated with augmentation of the nonplanar shape of the mitral annulus (ie, decreases NPA). This favorable change in the mitral annular geometry could possibly confer a structural advantage to MV repairs with the saddle rings.

The saddle shape of the mitral annulus is preserved across species and is believed to contribute toward stress reduction on the leaflets during coaptation [1]. Appreciation of the physiologic importance of the shape of the mitral annulus has resulted in increased consideration among clinicians of the use of surgical techniques that restore or augment the saddle shape of the mitral annulus during mitral valve (MV) repair [2–4]. Although there are no long-term studies, restoration of the saddle shape or the nonplanarity of the mitral annulus may prolong the durability of repair by reducing leaflet stress and therefore have

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impact on long-term outcome. Until recently, postrepair analysis of a repaired MV was limited to immediate post-cardiopulmonary bypass assessments of mechanical stability and the absence of significant regurgitation or stenosis. With the availability of three-dimensional (3D) transesophageal echocardiography (TEE) in the operating room (OR), the prerepair and postrepair assessments of the MV have evolved and improved considerably [5]. Particularly, 3D geometric analyses, which were once performed off-line and only in research laboratories, can be performed within minutes of data acquisition in the OR [6,7]. The ready availability of this data in the OR further enables analysis of the extent of geometric distortion of a repaired MV and the potential to guide us in the selection of the most appropriate annuloplasty device for a particular patient.

It is known that the mitral annulus tends to flatten with chronic mitral regurgitation and undergoes conformational changes after repair and application of annuloplasty devices [8–10]. Specifically, the changes in the nonplanarity of the annulus determine the degree of stress on the leaflets and possibly the durability of repair. The effects of specific annuloplasty rings on the saddle shape of the mitral annulus can be appreciated by measuring the prerepair and postrepair changes in valve structure, particularly the nonplanarity angle (NPA). For example, It has been demonstrated that flat annuloplasty rings lead to an increase in the NPA; ie, they make the mitral annulus more planar as compared with partial bands [7].

The design and structure of annuloplasty rings are constantly evolving. Currently, manufacturers are investing significant efforts in developing annuloplasty devices that limit the extent of geometric distortion on the MV. Some of these newly developed saddle-shaped annuloplasty rings have been introduced into clinical practice (Fig 1). These saddle-shaped rings have been shown to have a more uniform distribution of stress forces across the mitral leaflets after implantation in an animal study [11]. Application of these rings has also been shown to increase 3D leaflet curvature in an animal model [8]. We hypothesized that when compared to flat rings, saddle-shaped annuloplasty rings, by virtue of their shape, make the mitral annulus more nonplanar. In other words, when compared to flat rings, they would decrease the NPA after mitral valve repair for both ischemic and myxomatous MV disease.

Material and Methods

We compared the geometric changes in the MV before and after repair in electively scheduled patients (ischemic and myxomatous disease) with flat Carpentier-Edwards (CE) Physio rings (Edwards Lifesciences, Irvine, CA), Profile 3D (Medtronic, Minneapolis, MN) saddle-shaped rings, and St. Jude Medical rigid saddle ring (St Jude Medical, St Paul, MN) at our institution from January 2009 to December 2009. The study was carried out as part of a prospective observational Institutional Review Board approved protocol to analyze the changes in MV geometry with 3D echocardiography. The patients in this study were not randomized to receive any particular annuloplasty ring. The choice of annuloplasty ring was based on preference by the surgeon. The initial perioperative TEE examination was carried out after the induction of general anesthesia and endotracheal intubation and before surgical incision. All studies were performed on Philips Medical Systems IE-33 ultrasound systems (Andover, MA) utilizing an X7-2t multiplane TEE transducer capable of real-time 3D image acquisition. A comprehensive two-dimensional and Doppler TEE examination was performed according to published guidelines [12]. The 3D image acquisition of the MV was performed with the TEE probe in the midesophageal position and initiated with the scan plane at zero degree rotation. Imaging acquisition was completed by volumetric R-wave triggered imaging over 4 to 8 beats during a brief period of apnea to obtain a clear en-face (left atrial) view of the MV. During surgical implantation of the annuloplasty ring, the “hinge-points” of the saddle rings were aligned with the maximal commissural diameter of

the valve visualized during surgical exposure; ie, the echo-cardiographic plane used for measurement of the NPA (Fig 2). The same protocol was used for volumetric 3D image acquisition after completion of MV repair and separation from cardiopulmonary bypass (Fig 3). The data sets were immediately exported by portable hard drive to a Windows based laptop computer equipped with the TomTec (GmbH, Munich, Germany) "Image Arena Software," a commercially available software capable of geometric analysis of 3D MV with the volumetric ultrasound data sets utilizing the "Mitral Valve Assessment Package." The entire process of image export and analysis was performed within 2 to 3 minutes and the information was available in the OR immediately after the analysis was complete.

Mitral Valve Analysis

The methodology followed to geometrically analyze the MV has been described previously [6,7]. Briefly, the analysis of the 3D data sets was performed in a sequential workflow to analyze the mitral valve (Table 1). The mitral analysis was performed immediately after volumetric acquisition of the ultrasound data sets immediately after induction of general anesthesia and after successful separation from cardiopulmonary bypass. The final step in this mitral valve analysis automatically generates an en-face 3D view of the valve with the geometric parameters simultaneously displayed (Fig 4). The prerepair and postrepair data generated by these MV geometric analyses were then compared.

Statistical Analysis

Assessment of the change in the valve angle after ring placement in both ischemic and nonischemic cases was made using repeated measures analysis of variance, with Tukey-Kramer multiple comparisons test when comparing valve subtypes. Furthermore, the significance of changes in the NPA and other outcomes was assessed utilizing a dependent paired *t* test for pre and post comparisons and analysis of variance or independent group *t* test for postoperative comparisons across the different ring types, as appropriate. The *p* values less than 0.05 were considered significant unless stated otherwise. Windows Kwikstat (WINKS) SDA version 6 (Texassoft, Cedar Hill, TX), SPSS 14.0 (SPSS, Inc, Chicago, IL), and Microsoft Excel program (Microsoft Corp, Redmond, WA) were used to conduct the statistical test and analysis.

Results

A total of 40 patients completed the study. Four patients were excluded from the study due to insufficient data collection (2 for CE-Physio ring, 1 for St. Jude saddle ring, and 1 for Medtronic Profile 3D saddle ring). Therefore, analysis and comparison were performed on 36 patients (90%). Twenty-three mitral valve repairs were for ischemic-related MV disease and 13 were related to myxomatous disease (Table 2). A total of 18 (9 Medtronic and 9 St. Jude) patients had annuloplasties with saddle rings, and 18 patients had a flat ring placed (CE-Physio) (Table 3). Of the 23 repairs for ischemic MV disease, 11 received saddle rings (St. Jude and Medtronic) and 12 patients received flat rings (CE-Physio) (Table 4). Of the 13 MV repairs for myxomatous disease, 7 patients received saddle rings (St. Jude and Medtronic) and 6 patients had the CE-Physio ring implanted (Table 5).

We found that the difference in post-ring placement NPA was significantly affected by the ring subtype (Physio versus Medtronic versus St. Jude) by repeated measures ANOVA. The flat ring increased the angle, whereas the two saddle rings decreased the angle after surgery ($p < 0.01$ for both ring types; Fig 5). There was no difference in the postrepair NPA between the two saddle ring types. Also, there was no effect on the annular angle due to saddle ring placement for either ischemic or nonischemic reasons ($p = 0.91$). There were significant changes in all the analyzed geometric parameters after MV repair with either of

the saddle-shaped rings or with the flat ring (Tables 2; 3; 4). The saddle-shaped rings led to a statistically significant decrease (8% reduction from baseline) in the NPA (pre $145.46^{\circ} \pm 8.16^{\circ}$ to post $134.30^{\circ} \pm 11.63^{\circ}$). This represents an augmentation of the nonplanar or saddle shape of the MV annulus that occurred throughout the entire cohort (ischemic and myxomatous) of MV repairs using these rings (Table 2). In comparison, use of the flat CE-Physio rings resulted in an 11% increase of the NPA (pre $137.03^{\circ} \pm 13.86^{\circ}$ to post $148.64^{\circ} \pm 14.82^{\circ}$), which represents a flattening or loss of the nonplanar shape of the MV annulus (Table 2). The effects of these rings on NPA were observed irrespective of the MV pathology. In patients with ischemic disease, placement of saddle rings led to a 7% reduction in NPA (pre $145.48^{\circ} \pm 9.33^{\circ}$ to post $134.89^{\circ} \pm 13.01^{\circ}$) and the flat CE-Physio rings caused an almost 8% increase (pre $137.65^{\circ} \pm 15.24^{\circ}$ to post $147.68^{\circ} \pm 16.49^{\circ}$) (Table 3). In patients with myxomatous MV disease, saddle rings caused an 8% reduction (pre $145.43^{\circ} \pm 6.60^{\circ}$ to post $133.7^{\circ} \pm 9.96^{\circ}$) and the CE-Physio rings caused an 11% increase (pre $135.0^{\circ} \pm 11.86^{\circ}$ to post $150.57^{\circ} \pm 11.90^{\circ}$) in NPA. There was also no significant difference in the average post-NPA between the patients who received a Medtronic Profile 3D saddle ring ($134.4^{\circ} \pm 15.0$) (n = 9) and St. Jude Medical rigid saddle ring ($137.5^{\circ} \pm 7.4$) (n = 9).

Other than the NPA, both types of annuloplasty rings (flat and saddle) resulted in significant and similar changes in all other analyzed parameters of the MV geometry. Of note, reductions in the AP diameter and annular area were similar between the two types of annuloplasty devices (CE-Physio and the saddle-shaped rings).

Comment

The results of our study show that the type of annuloplasty device implanted during MV repair surgery is an important determinant of mitral annular changes after repair. We evaluated the effect of the recently introduced saddle-shaped rings from two manufacturers (Medtronic and St. Jude Medical) on mitral annular nonplanarity and compared them to the flat profile CE-Physio rings (Edwards Lifesciences). Our results demonstrate that the saddle-shaped rings decrease the NPA after repair; ie, they make the annulus more saddle shaped or nonplanar. In contrast, flat profile rings increase the NPA; ie, they result in a mitral annulus that is more planar or less saddle shaped (Table 2). This augmentation effect on the nonplanar shape of the mitral annulus with the saddle-shaped rings appears to occur whether the MV pathology requiring repair is ischemic or myxomatous in origin (Tables 3; 4). Both saddle-shaped and flat rings were found to impact all the mitral valve geometric parameters, which were analyzed in our study (Fig 4) (Tables 2; 3; 4). These findings give more credence to the intuitive thought that the MV structure undergoes significant conformational changes after application of any annuloplasty device (Figs 2; 3).

Mitral annular nonplanarity has generally been assessed in animal experiments or through the use of transthoracic and magnetic resonance imaging studies [3,13–22]. It is now established that of all the geometric parameters, the physiologic degree of nonplanarity of the mitral annulus confers the most structural strength and stability to the entire mitral apparatus [1]. The mitral subvalvular apparatus also exerts a torque force to help conform the mitral annulus into a saddle shape during systole [23]. The understanding of this unique structural design of the MV and its importance has led to the development of saddle-shaped annuloplasty rings to preserve-restore the natural saddle shape of the annulus after repair. The unique shape of these rings (Figs 1;2) comes by virtue of the elevation of their anterior and posterior horns and by their ability to reduce the AP diameter (Fig 2). This decreases the NPA and makes the annulus more saddle shaped. Calculation of the NPA by 3D echocardiography allows for the impact of specific annuloplasty devices, whether they be complete or partial rings, or flat or saddle shaped, to be assessed in real-time in the operating room rather than off line, or even more removed, from clinical extrapolation of experimental animal data [6,7].

The unfavorable change (ie, increase) in NPA with the application of full rings with a flat profile has been demonstrated in recent studies [7,10,24]. The flat rigid rings decrease and fix the anteroposterior diameter of the mitral annulus to optimize leaflet coaptation but abolish the dynamic systolic saddle configuration. This subjects both the MV leaflets and the subvalvular apparatus to higher degrees of stress as compared to saddle-shaped rings [11,23]. Flexible annuloplasty rings, on the other hand, seem to better preserve the native nonplanar shape of the annulus but do not prevent annular dilatation [7,15,25]. The results of our study show that saddle-shaped rings lead to a similar degree of reduction in the anteroposterior diameter of the MV annulus at the same time maintain its saddle shape. In this way they can augment leaflet coaptation and prevent further annular dilatation while reducing stress on the valve components. This reduction of stress may have the potential to improve the durability and longevity of MV repairs.

The augmentation of MV annular nonplanarity with implantation of saddle-shaped annuloplasty rings has been reported in an animal model [8]. Our study is a clinical report of a similar effect of saddle-shaped rings on the nonplanarity of human MV annuli. The reduction in NPA with implantation of saddle-shaped annuloplasty rings demonstrates that it is possible to restore the mitral annular nonplanarity to within physiologic range [7]. The NPA has been used as a measure of the saddle shape of the mitral annulus in previous studies [7,26,27]. With the clinical application of the 3D geometric mitral valve assessment, the appreciation of precise geometric changes associated with specific types of rings is beginning to achieve clinical relevance. It is quite possible that in future we may be able to select annuloplasty rings based on baseline geometric characteristics which are best suited to conform a particular mitral annulus to within physiologic range. The availability of 3D TEE has transformed MV geometric assessment from an intellectual curiosity to clinical relevance.

Limitations of the Study

We can identify certain limitations of our study. First, though we have demonstrated augmentation of mitral annular nonplanarity with saddle-shaped rings, we cannot say whether or not this actually results in a reduction of stress on the MV apparatus. However, several animal and experimental studies have demonstrated leaflet stress reduction with increasing nonplanarity of the mitral annulus. Further studies will be needed to assess whether or not a similar degree of leaflet stress reduction occurs in humans [8,23]. Second, long-term follow-up data will be needed to confirm the beneficial effects of this particular repair technique in prolonging the durability of MV repair.

Conclusion

The placement of any mitral valve annuloplasty rings during MV repair results in significant geometric changes in the MV annulus. In contrast to flat annuloplasty rings, application of saddle-shaped annuloplasty rings results in a decrease of the NPA or an augmentation of the saddle shape of the mitral annulus. This effect of augmentation of the saddle shape occurs whether the repair is being performed for ischemic or myxomatous MV disease. Restoration of normal physiologic shape through the application of a saddle-shaped annuloplasty ring may confer a structural advantage to the MV leaflets after repair by reducing stress on the MV apparatus.

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Fig 1. Different types of rings, which were used for comparative analysis of geometric changes after mitral valve repair being shown in different profiles. (1) Medtronic saddle ring; (2) St. Jude Medical rigid saddle ring; (3) Carpentier-Edwards Physio ring.

Fig 2. Implantation of the saddle-shaped annuloplasty ring in the mitral position. The “hinge points” of the annuloplasty rings are lined with the commissural diameter of the mitral valve. The non-planarity angle of the valve is then calculated as the angle subtended at the commissural diameter between the anterior and posterior horns of the mitral annulus.

Fig 3.

Figures showing various views of an implanted saddle-shaped ring. (A) Lateral three-dimensional echocardiographic view of an implanted saddle ring through the left atrium demonstrating the nonplanar configuration of the native mitral annulus. (B) An overlaid graphic to demonstrate the nonplanar configuration of the native mitral annulus shown in (A). (C) En-face (left atrial) "live" three-dimensional echocardiographic view of saddle-shaped mitral annulus after separation from cardiopulmonary bypass. (D) Left atrial image the implanted saddle-shaped ring shown in (C) during a mitral valve repair through a left atritomy.

Fig 4.

(A) Geometric parameters analyzed during three-dimensional reconstruction. An en-face image of the mitral valve with the aortic valve at 12 o'clock position. (AL-PM = anterolateral posteromedial diameter [distance between anterolateral and posteromedial landmarks]; AP = anteroposterior diameter [distance between anterior and posterior landmarks]; AV = aortic valve; CD = commissural diameter [mitral annular diameter at the level of the anterolateral and posteromedial commissure].) (B) Anterior annulus length: length of the anterior annulus between the two commissures. Posterior annulus length: length of the posterior annulus between the two commissures. (C) Annulus area: the area of the anterior annulus. (D) Nonplanarity angle: angle subtended between the anterior and posterior horns at the commissural diameter of the valve.

Fig 5.

Results of the analysis of variance test for assessment of changes in mitral annular nonplanarity angle with the saddle rings (Medtronic and St. Jude Medical) and the Physio flat ring (Edwards). The saddle rings caused a significant and equal reduction in the nonplanarity angle for myxomatous and ischemic mitral valves as compared to the Physio flat rings which caused an increase in the nonplanarity angle.

Table 1**Workflow of the Mitral Valve Geometric Analysis**

Parameter	Method	Details
1 Reference image setup	Two orthogonal views displayed	Aortic valve identified
2 Frame of interest	Echocardiographic frame to perform analysis	End-systolic frame
3 Landmark identification	Anterior, posterior, medial, and lateral landmarks	Landmarks identified on the frame of interest
4 Line of sight	En-face view of the mitral valve obtained	Dart tool of used to obtain this image
5 Mitral annular marking	Mitral annulus identified in 8 to 10 cut planes	Annulus marked between the identified landmarks
6 Commissural identification	Antero-lateral and posteromedial commissures identified	Commissures identified on an en-face view of the mitral valve
7 Line of coaptation	Coaptation point identified in 8 to 10 cut planes	Coaptation line displayed on the en-face view of the mitral valve
8 Geometric analysis	Automated generation of analysis	Annular dimensions, leaflet lengths, and nonplanarity angle described

Table 2

Demographic Characteristics

Breakdown of Patient Sample	Saddle Rings		Physio Rings		Total
	Male	Female	Male	Female	
Ischemic	6	5	8	4	23
Nonischemic	3	4	1	5	13
Total	11	7	9	9	36

Comparison Between all Saddle (Medtronic and St. Jude) and Physio Rings (Edwards Lifesciences) for Ischemic and Myxomatous Mitral Valves

Table 3

Variable	Comparison of Mitral Rings			
	Saddle Rings (n = 18)		Physio Rings (n = 18)	
	Prerepair	Postrepair	Prerepair	Postrepair
Commissural diameter (cm)	4.37 ± 0.70	3.51 ± 0.26	3.59 ± 0.55	2.69 ± 0.60
% Reduction	$p < 0.001^a$ 18.0 ± 14.6			$p < 0.001^a$ 24.4 ± 17.2
Nonplanarity angle(degrees)	145.46 ± 8.16	134.30 ± 11.63	137.03 ± 13.86	148.64 ± 14.82
% Reduction	$p < 0.001^a$ 7.7 ± 6.2			$p = 0.004^a$ -9.0 ± 10.6
Sphericity index	0.91 ± 0.11	0.80 ± 0.08	0.94 ± 0.09	0.84 ± 0.10
% Reduction	$p = 0.002^a$ 10.9 ± 12.2			$p < 0.001^a$ 10.5 ± 9.6
3D closure line length (cm)	4.57 ± 0.91	3.69 ± 0.80	4.59 ± 0.77	4.04 ± 0.57
% Reduction	$p = 0.004^a$ 18.2 ± 14.7			$p = 0.004^a$ 10.6 ± 14.3
AL PM diameter (cm)	4.62 ± 0.62	3.46 ± 0.25	3.90 ± 0.41	2.94 ± 0.47
% Reduction	$p < 0.001^a$ 24.3 ± 8.3			$p < 0.001^a$ 24.2 ± 13.1
AP Diameter (cm)	4.18 ± 0.62	2.75 ± 0.33	3.66 ± 0.41	2.46 ± 0.37
% Reduction	$p < 0.001^a$ 33.3 ± 10.1			$p < 0.001^a$ 32.5 ± 8.9
Annulus area (cm ²)	16.18 ± 3.90	7.98 ± 1.26	11.62 ± 1.97	6.13 ± 1.59

Variable	Comparison of Mitral Rings			
	Saddle Rings (n = 18)		Physio Rings (n = 18)	
	Prerepair	Postrepair	Prerepair	Postrepair
% Reduction	$p < 0.001^a$ 48.9 ± 10.7			$p < 0.001^a$ 46.7 ± 13.3
Annulus length (cm)	15.32 ± 1.90	11.03 ± 0.88	13.24 ± 1.17	9.48 ± 1.18
% Reduction	$p < 0.001$ 27.3 ± 7.5			$p < 0.001^a$ 28.1 ± 8.9
Anterior annulus length (cm)	6.62 ± 1.27	5.25 ± 0.63	5.13 ± 1.03	3.66 ± 0.90
% Reduction	$p < 0.001^a$ 18.3 ± 16.9			$p < 0.001^a$ 28.1 ± 8.9
Posterior annulus length (cm)	8.59 ± 1.14	5.78 ± 0.90	8.12 ± 0.51	5.82 ± 1.14
% Reduction	$p < 0.001^a$ 32.1 ± 11.2			$p < 0.001^a$ 28.3 ± 13.1
			$p = 0.351$	

^aStatistically significant.

AL PM = anterolateral-posteromedial diameter; AP = anteroposterior diameter; 3D = three dimensional.

Table 4

Prerepair and Postrepair Difference in Geometric Changes Between the Saddle Rings and Physio Rings for Ischemic Mitral Valve Repairs

	Ischemic Mitral Valves (n = 23)			
	Saddle Rings (n = 11)		Physio Rings (n = 12)	
	Prerepair	Postrepair	Prerepair	Postrepair
Commissural diameter (cm)	4.37 ± 0.72	3.50 ± 0.20	3.73 ± 0.92	2.73 ± 0.30
% Reduction	$p = 0.002^a$ 18.4 ± 7.4		$p = 0.003^a$ 23.0 ± 19.3	
Nonplanarity angle (degrees)	145.48 ± 9.33	134.89 ± 13.01	137.65 ± 15.24	147.68 ± 16.49
% Reduction	$p = 0.006^a$ 7.3 ± 7.0		$p = 0.057$ -7.9 ± 11.7	
Sphericity index	0.92 ± 0.11	0.78 ± 0.07	0.95 ± 0.08	0.83 ± 0.10
% Reduction	$p = 0.008^a$ 10.9 ± 12.2		$p = 0.003^a$ 12.4 ± 10.9	
3D closure line length(cm)	4.39 ± 0.65	3.59 ± 0.67	4.49 ± 0.60	4.06 ± 0.57
% Reduction	$p < 0.001^a$ 16.9 ± 17.8		$p = 0.046^a$ 8.7 ± 13.9	
AL PM diameter (cm)	4.57 ± 0.53	3.47 ± 0.25	3.78 ± 0.33	2.88 ± 0.52
% Reduction	$p < 0.001^a$ 23.3 ± 8.9		$p < 0.001^a$ 23.4 ± 14.0	
AP diameter (cm)	4.23 ± 0.65	2.72 ± 0.30	3.57 ± 0.26	2.39 ± 0.34
% Reduction	$p < 0.001^a$ 34.3 ± 12.0		$p < 0.001^a$ 32.9 ± 8.6	
Annulus area (cm ²)	16.01 ± 3.79	7.95 ± 1.08	11.08 ± 1.38	6.19 ± 1.94
% Reduction	$p < 0.001^a$ 48.0 ± 13.3		$p < 0.001^a$ 45.8 ± 14.5	
Annulus length (cm)	15.29 ± 1.73	10.99 ± 0.65	12.90 ± 0.97	9.24 ± 1.19
% Reduction	$p < 0.001^a$ 27.4 ± 8.2		$p < 0.001^a$ 28.1 ± 9.8	

Ischemic Mitral Valves (n = 23)				
Saddle Rings (n = 11)		Physio Rings (n = 12)		
	Prerepair	Postrepair	Prerepair	Postrepair
Anterior annulus length (cm)	6.80 ± 1.31	5.41 ± 0.69	4.95 ± 0.99	3.48 ± 0.98
% Reduction	$p = 0.003^a$ 18.3 ± 16.2		$p < 0.001^a$ 29.3 ± 17.4	
Posterior annulus length (cm)	8.30 ± 1.07	5.57 ± 0.45	7.97 ± 0.46	5.78 ± 1.29
% Reduction	$p < 0.001^a$ 31.8 ± 10.5		$p < 0.001^a$ 27.5 ± 15.4	

^a Statistically significant.

AL PM = anterolateral-posteromedial diameter; AP = anteroposterior diameter; 3D = three dimensional.

Table 5

Prerepair and Postrepair Differences in Geometric Parameters Between Saddle and Physio Rings for Myxomatous Mitral Valve Repair

	Nons ischemic Mitral Valves (n = 13)			
	Saddle Rings (n = 7)		Physio Rings (n = 6)	
	Prerepair	Postrepair	Prerepair	Postrepair
Commissural diameter (cm)	4.37 ± 0.70	3.53 ± 0.36	3.78 ± 0.73	2.95 ± 0.46
% Reduction	$p = 0.004^a$ 18.4 ± 7.4		$p = 0.042^a$ 20.1 ± 17.4	
Nonplanarity angle (degrees)	145.43 ± 6.60	133.7 ± 9.96	135.0 ± 11.86	150.57 ± 11.90
% Reduction	$p = 0.005^a$ 8.3 ± 5.1		$p = 0.020^a$ -11.2 ± 8.4	
Sphericity index	0.88 ± 0.12	0.82 ± 0.09	0.92 ± 0.09	0.85 ± 0.09
% Reduction	$p = 0.089$ 6.5 ± 9.0		$p = 0.028^a$ 6.6 ± 5.4	
3D closure line length(cm)	4.84 ± 1.23	3.86 ± 1.00	4.80 ± 1.08	4.02 ± 0.61
% Reduction	$p = 0.012^a$ 20.1 ± 8.9		$p = 0.055^a$ 14.3 ± 15.8	
AL PM diameter (cm)	4.69 ± 0.77	3.43 ± 0.23	4.15 ± 0.45	3.05 ± 0.36
% Reduction	$p < 0.001^a$ 25.8 ± 7.6		$p = 0.007^a$ 25.8 ± 12.0	
AP diameter (cm)	4.11 ± 0.60	2.80 ± 0.38	3.85 ± 0.60	2.60 ± 0.43
% Reduction	$p < 0.001^a$ 31.7 ± 4.9		$p = 0.003^a$ 31.8 ± 10.4	
Annulus area (cm ²)	16.44 ± 4.37	8.04 ± 1.59	12.68 ± 2.64	7.50 ± 1.99
% Reduction	$p < 0.001^a$ 50.2 ± 5.5		$p = 0.001^a$ 48.5 ± 11.4	
Annulus length (cm)	15.37 ± 2.28	11.10 ± 1.22	13.92 ± 1.56	9.97 ± 1.11
% Reduction	$p = 0.001^a$ 27.2 ± 7.0		$p < 0.001^a$ 28.2 ± 7.5	

Nonschemic Mitral Valves (n = 13)				
	Saddle Rings (n = 7)		Physio Rings (n = 6)	
	Prerepair	Postrepair	Prerepair	Postrepair
Anterior annulus length (cm)	6.34 ± 1.26	5.00 ± 0.44	5.50 ± 1.10	4.03 ± 0.64
% Reduction	$p = 0.037^a$ 18.4 ± 19.4		$p = 0.009^a$ 25.5 ± 12.0	
posterior annulus length (cm)	9.06 ± 1.16	6.10 ± 1.33	8.42 ± 0.52	5.92 ± 0.84
% Reduction	$p = 0.001^a$ 32.6 ± 13.0		$p = 0.002^a$ 29.8 ± 7.9	

^a Statistically significant.

AL PM = anterolateral-posteromedial diameter; AP = anteroposterior diameter; 3D = three dimensional.