

# Early Changes of Left Ventricular Geometry and Function after Surgical Ventricular Restoration and Mitral Valve Annuloplasty: Magnetic Resonance Imaging

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**Purpose** : We sought to determine the early change of ventricular geometry and function after concomitant surgeries of modified Dor procedure and mitral valve annuloplasty by using magnetic resonance imaging.

**Materials and Methods** : We enrolled 21 patients with dilated heart failure who underwent modified Dor procedure (n=8), mitral valve annuloplasty (n=6), or both surgeries (n=7). Cine MRI was used to assess left ventricular dimensions and function before and after surgery. We measured the left ventricular end-diastolic and end-systolic volumes and the dimensions of the left ventricular long-axis and short-axis. Left ventricular stroke volume, ejection fraction, and sphericity index were calculated from these measurements. These parameters were analyzed and compared between three different surgery groups to explain the combined effect of the concomitant surgeries.

**Results** : MRI was performed within average  $12 \pm 15$  days (range 1 - 58 days) before and  $38 \pm 50$  days (range 7 - 231 days) after the surgery. The patients who underwent concomitant surgeries had more profound enlargement of left ventricle and decreased contractility prior to surgery than those in the patients who underwent single surgical procedure. Left ventricular end-diastolic volume and end-systolic volume significantly decreased in all patients regardless of surgery type after surgery. Ejection fraction significantly increased only in the patients who got modified Dor procedure without mitral valve annuloplasty (25.4% to 40.7%). Sphericity index increased in patients with modified Dor procedure but decreased in patients with mitral valve annuloplasty (0.65 to 0.78 vs. 0.75 to 0.65). In the patients who underwent concomitant surgeries showed no significant change in sphericity index after surgery.

**Conclusion** : The early change of the left ventricular geometry and function after the concomitant surgeries with modified Dor procedure and mitral valve

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annuloplasty in patients with dilated heart failure includes a marked reduction in left ventricular volume and in stroke volume. The shape of the left ventricle does not change because the effect of sphericity index decrease from mitral valve annuloplasty is counteracted by the effect of sphericity index increase from modified Dor procedure. Improvement of left ventricular ejection fraction is not the early change after the concomitant surgeries.

**Index words :** Surgical Ventricular Restoration  
Left Ventricular Volume Reduction Surgery  
Dor Procedure  
Mitral Annuloplasty  
Magnetic Resonance Imaging

## **Introduction**

Surgical ventricular restoration is increasingly being utilized in the treatment of heart failure in dilated heart. The surgical strategy is composed of left ventricular volume reduction and restoration of the natural elongated shape of the ventricle to reduce wall stress and to improve ventricular function. Endoventricular circular patch plasty is the most widely used technique of the ventricular restoration surgery, which is named Dor procedure to credit Dr. Vincent Dor who first introduced it in 1985.

In dilated cardiomyopathy, Dor procedure is usually performed combined with coronary artery bypass grafting if there is any significant stenosis in coronary arteries and with ring annuloplasty (1) if there is a significant functional mitral regurgitation combined with ventricular dilatation. As bypass grafting is essential and usually performed prior to the Dor procedure itself during the surgery, the effect of Dor procedure from that of bypass grafting cannot be considered separately. Otherwise, mitral valve annuloplasty in dilated cardiomyopathy is beneficial because the presence of mitral insufficiency has a negative influence on survival with ischemic or idiopathic dilated cardiomyopathy (2). Although studies have reported the Dor procedure to be safe, the effect of the isolated Dor procedure is not well known. Because Dor procedures are often performed with concomitant mitral valve annuloplasty, improvement in postoperative systolic function and change of left

ventricular geometry may be from mitral valve annuloplasty and not from the Dor procedure (3 - 5).

Therefore we measured volume and function changes of the left ventricle in patients who underwent only the Dor procedure and in patients who underwent only mitral valve annuloplasty and compared these results with those in patients who underwent concomitant the Dor procedure and mitral valve annuloplasty to explain the effects in combined procedures. We used magnetic resonance imaging (MRI) to evaluate the geometry and function of the left ventricle before and after the surgery.

## **Materials and Methods**

### **Subjects**

We enrolled 21 patients with dilated heart failure who underwent modified Dor procedure or/and mitral valve annuloplasty. Eight patients underwent only modified Dor procedure, 6 patients underwent only mitral valve annuloplasty, and 7 patients underwent concomitant modified Dor procedure and mitral valve annuloplasty. Patients' demographic data of preoperative cardiac function on each group were summarized on Table 1. MRI was used to assess left ventricular dimensions and function. Mitral regurgitation was evaluated by echocardiography. Coronary angiography was performed in all patients.

Modified Dor procedure as a left ventricular volume reduction surgery was performed in patients with NYHA functional class III or IV and left ventricular ejection fraction below 30% (6). Patient were

considered suitable for left ventricular volume reduction surgery if they demonstrated an enlarged left ventricle accompanied by left ventricular dysfunction with either dyskinetic or akinetic apical segments after myocardial infarction and had symptoms of angina, congestive heart failure, ventricular tachycardia or a combination of these.

Mitral valve annuloplasty was performed if mitral regurgitation was severe greater than grade 2 or mitral annulus diameter measured more than 35 mm with any grade of mitral regurgitation. The degree of mitral insufficiency was graded from 0 to 4 in a semi-quantitative way. Mitral valve leakage was considered secondary to left ventricular enlargement if echocardiography showed central regurgitation associated with enlarged left ventricle. Mitral annulus size was measured on cine-MRI.

Modified Dor procedure and mitral valve annuloplasty were performed at once if a patient met the criteria of both surgeries.

### Surgical technique

For the modified Dor procedures, the apical left ventricle was opened and a circumferential purse-string suture was placed at the base of both papillary muscles to reduce the diameter of the left ventricle. In ischemic cardiomyopathy, the transition between infarcted aneurysm and uninfarcted myocardium was determined by inspection and palpation. All dyskinetic portions of the anterior wall and septum were excluded. The endoventricular circular suture described by Dor was performed with a 2/0 prolene purse string. Other details about this surgical procedure in these patients have been described in a previous report (7). Coronary artery bypass surgery was performed for any significantly stenotic arteries. Concomitant mitral valve annuloplasty was performed if the measurement of regurgitation and annular size met the criteria for surgery through opened left ventricle. In patients who underwent only mitral valve annuloplasty, the mitral valve was exposed by a transeptal incision. The mitral valve was repaired

**Table 1.** Patients' Demographic and Preoperative Characteristics

	Modified Dor Procedure	Mitral Valve Annuloplasty	Modified Dor Procedure & Mitral Valve Annuloplasty
Number of patients	8	6	7
Age (years)	58.2 ± 9.9	58.7 ± 13.3	57.1 ± 6.6
Sex (men:women)	8:0	5:1	7:0
Postoperative days (week) on MRI	41 ± 31 (6 weeks)	60 ± 85 (8 - 9 weeks)	17 ± 7 (2 - 3 weeks)
BSA (m <sup>2</sup> )	1.65 ± 0.16	1.74 ± 0.15	1.74 ± 0.12
LVEDV (ml)	235.2 ± 61.5	232.1 ± 44.2	368.2 ± 106.8
LVESV (ml)	177.9 ± 60.3	163.2 ± 43.6	295.9 ± 114.2
LVSV (ml)	57.4 ± 20.2	68.9 ± 21.2	72.3 ± 11.4
Long-axis length (cm)	94.7 ± 8.8	91.2 ± 4.6	97.3 ± 7.8
Short-axis diameter (cm)	61.3 ± 7.5	67.6 ± 5.0	80.3 ± 9.3
Sphericity index	0.65 ± 0.03	0.75 ± 0.03	0.83 ± 0.03
EDVI (mL/m <sup>2</sup> )	145.1 ± 15.1	134.5 ± 10.8	211.2 ± 20.8
ESVI (mL/m <sup>2</sup> )	110.0 ± 14.2	95.3 ± 11.5	169.4 ± 22.6
SVI (mL/beat/m <sup>2</sup> )	35.1 ± 12.2	39.3 ± 9.2	41.8 ± 7.5
Long-axis length index	57.8 ± 6.0	54.3 ± 6.0	56.2 ± 6.1
Short-axis diameter index	37.6 ± 6.4	39.1 ± 3.1	46.2 ± 4.2
EF (%)	25.4 ± 3.6	30.4 ± 4.2	21.3 ± 2.8
MR grade	0.5 ± 0.9	3.3 ± 0.8	3.3 ± 1.0
NYHA III-IV (%)	100	100	100
Number of Grafts	2.5 ± 1.1	1.8 ± 1.7	1.9 ± 1.3
Myocardial Infarction (%)	63 (5/8)	33 (2/6)	86 (6/7)
3-vessel disease (%)	63 (5/8)	50 (3/6)	36 (2/8)

BSA: body surface area, LVEDV: left ventricular end-diastolic volume, LVESV: left ventricular end-systolic volume, LVSV: left ventricular stroke volume, EDVI: left ventricular end-diastolic volume index, ESVI: left ventricular end-systolic volume index, SVI: left ventricular stroke volume index, EF: left ventricular ejection fraction, MR: mitral regurgitation, NYHA: New York Heart Association

according to the Bolling annuloplasty technique using a Cosgrove band, sutured on the posterior leaflet.

**MRI protocol**

Cardiac MRI was performed before and after the surgery. MRI was performed with subjects positioned supine in a 1.5-T MR unit (Gyrosan Intera; Philips medical system, Best, the Netherlands). Cine MRI was performed with balanced TFE (turbo field echo, 25 phases), which included short-axis, two-chamber and four-chamber views. Imaging parameters included the following: typical repetition time = 3.4 ms, echo time = 1.7 ms, flip angle = 50°, field of view = 360 mm, matrix 256 × 256, slice thickness = 10 mm, effective temporal resolution = 40 ms, number of signal average = 1, breath hold duration per slice = 14~16 s. The short-axis imaging encompassed the entire left ventricle.

**Analysis of MRI**

Endocardial left ventricular borders were manually traced at end-diastole and at end-systole. In left ventricular end-diastolic volume (LVEDV) and end-

systolic volume (LVESV) were measured by using Simpson's rule. We defined end-diastole as the first image of the cine-imaging set. End-systole was defined as the phase of the smallest volume in a total sum of every slice. From the measured LVEDV and LVESV, we calculated left ventricular stroke volume (LVSV) and ejection fraction (EF). We measured the dimensions of the left ventricular chamber at both end-diastole and end-systole. The dimension of the left ventricular long axis (long-axis length) was defined as a linear distance from the midpoint of the mitral annulus plane to the apex, and the dimension of the short axis (short-axis diameter) was defined as the linear distance from the anterior endocardium to the posterior endocardium at the midpapillary muscle plane. These dimensions were measured in end-diastole. Sphericity index was calculated as a ratio of short-axis diameter to long-axis length.

**Statistical analysis**

Descriptive anthropomorphic characteristics are presented as mean ± standard deviation. Analysis of variance (ANOVA) was used to assess differences

**Table 2.** Postsurgical Changes in Geometry and Function of Left Ventricle

		Preoperative	Postoperative	p-value
Modified Dor Procedure (n=8)	EDV (mL)	235 ± 61.5	170.3 ± 36.1	0.007
	ESV (mL)	177.9 ± 60.3	102.7 ± 20.9	0.001
	SV (ml)	57.4 ± 20.0	67.6 ± 17.3	0.128
	EF (%)	25.4 ± 3.6	40.7 ± 3.9	0.001
	Long-axis length (mm)	94.7 ± 8.8	74.3 ± 10.7	0.001
	Short-axis diameter (mm)	61.3 ± 7.5	57.2 ± 6.1	0.108
	Sphericity Index	0.650 ± 0.03	0.779 ± 0.04	0.008
Mitral Valve Annuloplasty (n=6)	EDV (ml)	232.1 ± 44.2	179.2 ± 37.4	0.005
	ESV (ml)	163.2 ± 43.6	121.2 ± 29.9	0.006
	SV (ml)	68.9 ± 21.2	57.9 ± 18.4	0.229
	EF (%)	30.4 ± 4.2	34.3 ± 6.3	0.327
	Long-axis length (mm)	91.2 ± 4.6	92.4 ± 4.4	0.321
	Short-axis diameter (mm)	67.6 ± 5.0	60.0 ± 4.7	0.008
	Sphericity Index	0.745 ± 0.03	0.652 ± 0.03	0.018
Modified Dor Procedure & Mitral Valve Annuloplasty (n=7)	EDV (mL)	368.2 ± 106.8	256.4 ± 92.6	0.002
	ESV (mL)	295.9 ± 114.2	208.4 ± 51.7	0.003
	SV (mL)	72.3 ± 11.4	48.0 ± 18.7	0.005
	EF (%)	21.3 ± 2.8	20.8 ± 3.6	0.771
	Long-axis length (mm)	97.3 ± 7.8	87.9 ± 8.6	0.003
	Short-axis diameter (mm)	80.3 ± 9.3	74.2 ± 10.0	0.036
	Sphericity Index	0.827 ± 0.03	0.848 ± 0.04	0.644

EDV: left ventricular end-diastolic volume, ESV: left ventricular end-systolic volume, SV: left ventricular stroke volume, EF: left ventricular ejection fraction

among groups. Two-tailed Student test for paired data was used when appropriate. A p-value less than 0.05 was considered significant. All the analysis was done using an SPSS package (Version 12.0; Statistical Package for the Social Sciences, Chicago, IL). Left ventricular parameters were conducted after adjustment for subject body surface area (BSA).

**Results**

MRI was performed with an interval of average 12 ± 15 days (range 1-58 days) before and 38 ± 50 days (range 7- 231 days) after the surgery. The postsurgical changes are summarized in Table 2 and 3.

**Postsurgical change in modified Dor procedure**

The LVEDV and LVESV significantly decreased. The LVSV did not significantly change. The EF significant increased from 25.4% to 40.7%. The long-axis length significantly decreased from 94.7 cm to 74.3 cm, however the short-axis diameter did not change. The sphericity index increased from 0.65 to 0.78. The indices of LVEDV, LVESV, LVSV, long-axis length, and short-axis diameter showed the same tendency of changes as the unstandardized data.

**Postsurgical change in mitral valve annuloplasty**

The LVEDV and LVESV significantly decreased. The

LVSV did not significantly change. The EF did not significantly change. The Long-axis length significantly decreased from 67.6 cm to 60.0 cm however, the short-axis diameter did not significantly change. The sphericity index significantly decreased from 0.75 to 0.65. The LVEDV, LVESV, LVSV, long-axis length, and short-axis diameter showed the same tendency of changes as the unstandardized data.

**Postsurgical change in concomitant modified Dor procedure and mitral valve annuloplasty**

The LVEDV and LVESV significantly decreased. The LVSV significantly decreased from 72 ml to 48 ml. The EF did not significantly change. The Long-axis length and the short-axis diameter significantly reduced. The sphericity index showed no significant change. The LVEDV, LVESV, LVSV, long-axis length, and short-axis diameter showed the same tendency of changes as the unstandardized data.

**Comparison of Different Surgeries**

The LVEDV and LVESV were significant decreased in all patients regardless of surgery type done. The EF was significant increased only in the patients who got modified Dor procedure without mitral valve annuloplasty. The left ventricular short-axis diameter was significant decreased in the patients who underwent mitral valve annuloplasty with or without

**Table 3.** Postsurgical Changes of Geometry and Function of Left Ventricle: Standardized with Body Surface Area

		Preoperative	Postoperative	p-value
Modified Dor Procedure (n = 8)	EDVI (ml/m <sup>2</sup> )	145.1 ± 15.1	103.5 ± 7.3	0.009
	ESVI (ml/m <sup>2</sup> )	110.0 ± 14.2	62.6 ± 7.4	0.002
	SVI (ml/m <sup>2</sup> )	35.1 ± 12.2	40.9 ± 9.0	0.134
	Long-axis length index (cm/m <sup>2</sup> )	57.8 ± 6.0	45.2 ± 5.8	0.001
	Short-axis diameter index (cm/m <sup>2</sup> )	37.6 ± 6.4	34.9 ± 4.5	0.095
Mitral Valve Annuloplasty (n = 6)	EDVI (ml/m <sup>2</sup> )	134.5 ± 10.8	104.0 ± 10.1	0.004
	ESVI (ml/m <sup>2</sup> )	95.3 ± 11.5	71.0 ± 12.2	0.008
	SVI (ml/m <sup>2</sup> )	39.3 ± 9.2	33.1 ± 8.0	0.208
	Long-axis length index (cm/m <sup>2</sup> )	52.9 ± 6.0	53.6 ± 4.9	0.375
	Short-axis diameter index (cm/m <sup>2</sup> )	39.1 ± 3.1	34.8 ± 4.4	0.006
Modified Dor Procedure & Mitral Valve Annuloplasty (n = 7)	EDVI (ml/m <sup>2</sup> )	211.2 ± 20.8	146.9 ± 18.5	0.002
	ESVI (ml/m <sup>2</sup> )	169.4 ± 22.6	119.0 ± 19.5	0.003
	SVI (ml/beat/m <sup>2</sup> )	41.8 ± 7.5	27.9 ± 11.4	0.006
	Long-axis length index (cm/m <sup>2</sup> )	56.2 ± 6.1	50.7 ± 5.3	0.003
	Short-axis diameter index (cm/m <sup>2</sup> )	46.2 ± 4.2	42.8 ± 5.8	0.028

EDVI: left ventricular end-diastolic volume index, ESVI: left ventricular end-systolic volume index, SVI: left ventricular stroke volume index

modified Dor procedure. The left ventricular long-axis length was significantly decreased in the patients who underwent modified Dor procedure with or without mitral valve annuloplasty.

The sphericity index increased in patients with modified Dor procedure but decreased in patients with mitral valve annuloplasty. In the patients who underwent modified Dor procedure with mitral valve annuloplasty showed no significant change of the sphericity index after the surgery. These are summarized in Table 4.

### Discussion

#### Postsurgical change in modified Dor procedure

In ischemic cardiomyopathy, coronary artery bypass grafting surgery can be an effective procedure, but the functional recovery is not sufficient and the recurrence of heart failure is high if ventricular remodeling has already occurred. Dor et al. reported another type of left ventricular volume reduction surgery, endoventricular circular patch plasty in 1985 for the dilated heart failure (8). The Dor procedure has been proved to improve pump function, clinical status, and survival, even in patients with severe cardiac dysfunction and now became one of the most widely used method among the various surgical ventricular restoration methods. Surgical ventricular restoration in patients with dilated heart failure constitutes ventricular volume reduction by elimination of dysfunctional myocardium and restoration of natural elliptical shape of left ventricle.

According to a previous animal study, after Dor procedure, left ventricular volume significantly reduces in 2 weeks then ejection fraction significantly increases

in 6 weeks (9). In a study with an angiographic follow-up in human patients, significant reduction in left ventricular volumes and an increase in EF after Dor procedure have been reported. Dor procedure shortens long-axis length but does not shorten short-axis diameter (10). In the present study, we demonstrated by using MRI that the patients who underwent modified Dor procedure without mitral valve annuloplasty showed compatible results with those of the previous reports on a mean post-operative day of 41. In the patients who underwent modified Dor procedure, surgical reduction of left ventricular volume by removing dysfunctional myocardium resulted in marked decrease of LVEDV and LVESV. However, the ratio of volume reduction was much higher in LVESV than in LVEDV (42.2% > 27.5%). However, LVSV did not significantly increase while EF significantly increased. It is attributable to contractility improvement from recovered circulation by bypass grafting, elimination of uncontractile myocardium or both. While long-axis length was shortened, short-axis diameter was not shortened after surgery. Thus sphericity index rather increased post-operatively. Despite a more spherical postoperative left ventricular chamber, systolic pump function improved.

#### Postsurgical change in mitral valve annuloplasty

An increase in left ventricular end-systolic volume and a distortion of shape of left ventricle are associated with inadequate approximation of the mitral tetrahedron during systole, which consequently leads to functional mitral regurgitation (11). The effects of mitral valve annuloplasty in these patients are provided by two mechanisms including elimination of mitral regurgitation and reduction of short-axis diameter.

**Table 4.** Comparison of Early Effects on Geometry and Function of Left Ventricle after Modified Dor Procedure, Mitral Valve Annuloplasty, and Concomitant Surgery

	Modified Dor Procedure	Mitral Valve Annuloplasty	Modified Dor Procedure + Mitral Valve Annuloplasty
EDVI			
ESVI			
EF		—	—
Long-axis length index		—	
Short-axis diameter index	—		
Sphericity Index			—

EDVI: left ventricular end-diastolic volume index, ESVI: left ventricular end-systolic volume index, EF: left ventricular ejection fraction, : increase, : decrease, —: no change

Nicolini et al. reported that mitral valve annuloplasty improved left ventricle ejection fraction from  $28.9\% \pm 5.2\%$  preoperatively to  $35.4\% \pm 8.1\%$  (1). Left ventricular volume and sphericity index decrease after surgery (12).

In the present study, mitral valve annuloplasty eliminated mitral regurgitation resulting in a decrease of LVEDV and LVESV with similar ratio (22.8% vs. 25.8%). Total LVSV slightly decreased regardless of change of the net stroke volume ejecting into the aorta. EF is mildly increased which was not statistically significant. No significant improvement of EF can be accounted for by depressed contractility from underlying cardiomyopathy. The length of LV did not change but the short-axis diameter significantly decreased. Thus sphericity index decreased and the shape became more elliptical.

#### ***Postsurgical change in concomitant modified Dor procedure and mitral valve annuloplasty***

Volume reduction surgery in patients with dilated heart failure is usually accompanied with mitral insufficiency repair. Post-infarction left ventricles are characterized by changes in shape and function frequently complicated by functional mitral regurgitation, leading to cardiac dysfunction and clinical heart failure, which heavily affect survival. Therefore mitral annuloplasty is important to reduce failure or delayed improvement rate of surgical ventricular restoration. In addition, mitral annulus size is not decreased after surgical ventricular restoration without mitral valve annuloplasty (13). In carefully selected patients with dilated cardiomyopathy with a cardiac output less than 2.5, short-axis diameter more than 7.0 cm, NYHA class exceeding III on maximal medical therapy, the Dor procedure combined with mitral valve annuloplasty achieves short-term results comparable to that after heart transplantation. In a study for the effects of the surgery, one-year post-operatively, LVSV index improved from 25.9 to 40.3 ml/m<sup>2</sup> whereas short-axis diameter decreased from 8.4 cm to 6.6 cm (14). LVEDV and LVESV were decreased and EF improved toward 1 year, coinciding with the improvement of clinical symptoms, potentially indicating a functional remodeling after the surgery (15).

In the present study, LVEDV, LVESV, and short-axis

diameter were profoundly increased and greater than those of other groups pre-operatively. The LVEDV and LVESV significantly decreased with a similar ratio (30.3% vs. 29.6%) after the surgery. Therefore The EF was not significantly changed after the surgery. The patients with concomitant modified Dor procedure and mitral valve annuloplasty, physical reduction of LVEDV and elimination of mitral regurgitation resulted in significant LVSV reduction (33.6%) even though increased contractility after the surgery might compensate the reduction of stroke volume. However, preoperative heart failure and LV dilatation were severe in these patients, so the contractility recovery was not as good as expected. Both the long-axis length and short-axis diameter significantly decreased, which could be explained as a direct effect of each surgical procedure.

In summary, LVEDV and LVESV decreased after either surgical procedures or concomitant surgeries. However left ventricular EF in concomitant surgeries did not show a significant improvement because the patients indicated for concomitant surgeries had significantly more dilated heart and decreased contractility than the patients indicated only for either surgery. It was probably an early follow-up to evaluate the recovery of contractility in patients with concomitant surgeries. Marked reduction of stroke volume after concomitant surgeries reflected much reduction of ventricular volume and elimination of large amount of mitral regurgitation in these patients. Shortening of long-axis length from modified Dor procedure and shortening of short-axis diameter from mitral valve annuloplasty directly contributed to insignificant change of sphericity index of left ventricle after concomitant surgeries.

#### ***Limitations***

Our study has some limitations. The first was that the patients were clinically heterogeneous; most of them were ischemic dilated cardiomyopathy but some were idiopathic dilated cardiomyopathy. In addition, each surgical procedure had different indication and the preoperative status was different among surgical groups. The second is that the effect of coronary bypass grafting could be a confounding factor in interpreting the results. However, it is difficult to separate the effect of bypass surgery from the surgeries we evaluated.

## Conclusion

The early change of left ventricular geometry and function after concomitant modified Dor procedure and mitral valve annuloplasty in patients with dilated heart failure includes marked reduction of left ventricular volume and stroke volume. The shape of left ventricle does not change because the effect of sphericity index decrease from mitral valve annuloplasty is counteracted by the effect of sphericity index increase from modified Dor procedure. An improvement of left ventricular ejection fraction is not the early change after concomitant surgeries.

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