

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

4,800

Open access books available

122,000

International authors and editors

135M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.  
For more information visit [www.intechopen.com](http://www.intechopen.com)



# Surgical Ventricular Restoration for Ischemic Cardiomyopathy with Functional Mitral Regurgitation

Masanori Hirota, Shintaro Katahira, Joji Hoshino, Yasuhisa Fukada, Taichi Kondo, Takayuki Gyoten, Yuichi Notomi and Tadashi Isomura  
*Department of Cardiovascular Surgery, Hayama Heart Center, Kanagawa, Japan*

## 1. Introduction

Ischemic cardiomyopathy (ICM) is defined as diffuse akinesis of the ventricle after myocardial ischemia<sup>1</sup>). A subset of patients with ICM develop progressive heart failure as a consequence of adverse left ventricular (LV) remodeling, leading to a depressed ejection fraction, a dilated LV, a large akinetic region of the myocardium, an abnormal globular shape to the ventricular chamber, and functional mitral regurgitation (MR)<sup>2-5</sup>). Although a dilated LV with poor cardiac function is a risk by itself, coexisting functional MR worsens the prognosis of ICM<sup>6,7</sup>). Thus, for patients with ICM and functional MR, it is very important to repair the geometric changes of LV remodeling and to decrease the extent of functional MR.

For patients with ICM, surgical ventricular restoration (SVR) is an established treatment to reduce ventricular size and restore the elliptical shape of the LV<sup>8-12</sup>). Anatomical restoration by SVR may decrease the severity of MR, through various mechanisms, including reduction of ventricular dimensions, lowering of end systolic volumes, and restoration of blood flow to the ischemic region of the mitral subvalvular apparatus<sup>13,14</sup>). However, concomitant procedures for the mitral valve are required for further reduction of functional MR. In this chapter, our therapeutic strategy for patients with ICM is demonstrated, and we describe the details of the surgical techniques of SVR and mitral valve surgery.

## 2. Patients

Between May 2000 and May 2010, SVR was performed in 335 patients with ICM (n=199) and non-ischemic cardiomyopathy (n=136). Of the 199 patients with ICM, 88 had concomitant mitral valve surgery for functional MR.

These patients with ICM and functional MR included 77 males and 11 females, ranging in age from 32 to 83 years (mean, 61±10 years). The preoperative New York Heart Association (NYHA) functional class was class III for 55% (48/88) and class IV for 45% (40/88). Preoperative heart failure was medically controlled with inotropes in 34 patients (39%), and 2 of these patients (2%) required intra-aortic balloon pumping (IABP). Due to uncontrollable

heart failure and worsening multiorgan failure, an emergent operation was performed in 12 patients (14%).

### 3. Materials and methods

#### 3.1 Assessment of cardiac geometry and regional function of the LV

Two-dimensional echocardiography was used to evaluate cardiac geometry, including dimensions and LV volume, valvular morphology, and the subvalvular apparatus. As indices of LV volume, the LV end-systolic and end-diastolic volume indices (LVESVI and LVEDVI) were calculated.

Regional LV function was examined by cardiac magnetic resonance imaging (MRI)<sup>15,16</sup> and color kinesis echocardiography<sup>17</sup>. Regional LV strain was assessed by speckle-tracking echocardiography under normal and dobutamine-stress conditions<sup>18</sup>.

##### a. Cardiac MRI

Cardiac MRI is a medical imaging technology for the non-invasive assessment of cardiac structure and function. Although it shows the precise myocardial anatomy in normal hearts, it is also useful for post-ischemic myocardial assessment<sup>15,16</sup>. To investigate LV wall motion, MRI images were obtained by cine acquisition. The depth and extension of the scarred LV wall were evaluated with 4 MRI projections. The 4-chamber view was used to assess the septum and lateral wall. The 2-chamber view (the vertical long-axis view) was useful for the anterior and posterior walls of the LV. The 3-chamber view (the LV outflow tract view) provided a detailed analysis of the mitral subvalvular apparatus. The short-axis view enabled a staged analysis of the septum and papillary muscles. Late gadolinium enhancement was also performed to investigate the irreversible myocardium of the LV wall<sup>19</sup>.

##### b. Color kinesis echocardiography

Color kinesis is a non-invasive technology for the echocardiographic assessment of LV wall motion based on acoustic quantification<sup>17</sup>. This technique automatically detects endocardial motion in real time using integrated backscatter data to identify pixel transitions from blood to tissue during systole on a frame-by-frame basis. We have reported the usefulness of intra-operative color kinesis echocardiography under cardiopulmonary bypass (CPB) assist for patients with idiopathic dilated cardiomyopathy<sup>20</sup>. LV wall motion was observed by direct vision of the cardiac echogram (HP SONO 5500; Agilent Technologies, Palo Alto, CA, USA) under different preloads controlled by CPB (volume reduction test). The objective of this test was to assess the akinetic region of the LV wall for SVR.

##### c. Speckle-tracking echocardiography

Speckle-tracking echocardiography is a unique imaging technique that analyzes multidirectional components of LV deformation within an ultrasonic window by tracking interference patterns and natural acoustic reflections<sup>21</sup>. The tracking system is obtained by automatic measurement of the distance between 2 pixels of an LV segment during the cardiac cycle, independent of the angle of insonation<sup>22,23</sup>.

Echocardiography was carried out using a Vivid 7 ultrasonography machine (GE Medical Systems, Milwaukee, WI, USA) with an M3S probe. Short-axis images from the mid-level (i.e., papillary muscle level) of the LV were obtained from the parasternal window to assess myocardial segmental viability and LV dyssynchrony. Caution was exercised to ensure

short-axis images with circular cross-sections and minimal out-of-plane movement. Short-axis images were analyzed by the EchoPAC platform (2DS software package, version 7; GE Medical Systems), which uses a speckle-tracking technique to derive rotation and strain for selected regions of the myocardium<sup>24</sup>. LV torsion is also calculated automatically from the LV basal and apical rotation data in the platform. For assessing segmental myocardial viability, the myocardial region obtained from the short-axis images of the midlevel LV was divided into four segments (septal, anterolateral, posterior, inferoseptal), and the circumferential strain profile was analyzed, which is closely related to myocardial viability<sup>25,26</sup>.

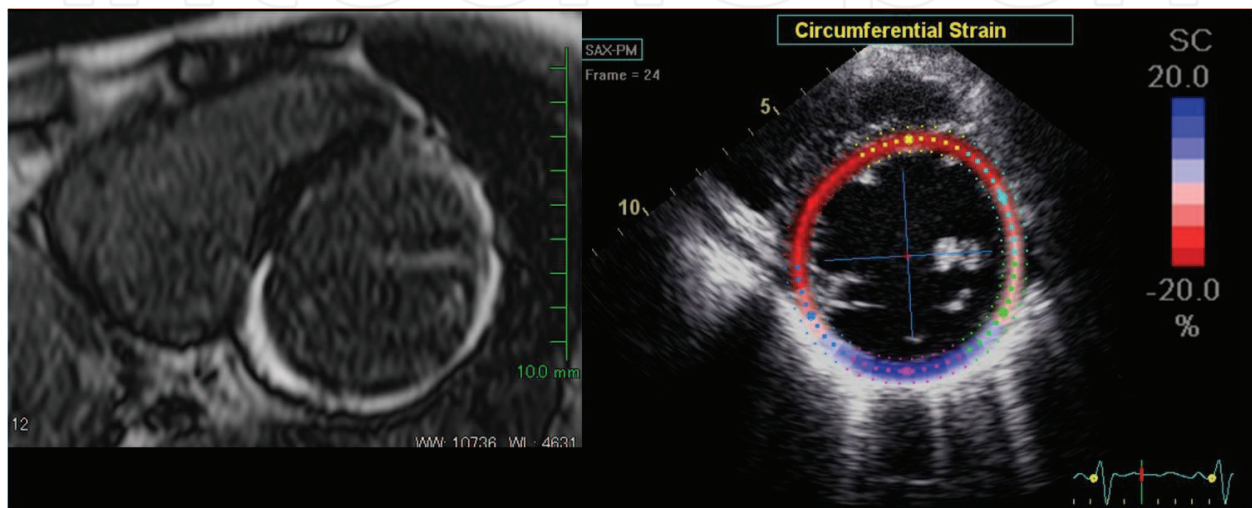


Fig. 1. Late gadolinium enhancement of cardiac magnetic resonance imaging (in the left panel) and two-dimensional speckle-tracking echocardiographic imaging (in the right panel) in a representative case with ischemic cardiomyopathy. Severe ischemic injury and a suggestion of fibrotic change (a tissue characteristic) are depicted in the lateral, posterior, and inferoseptal segments by late gadolinium enhancement, while end-systolic circumferential strain of speckle-tracking echocardiographic imaging detected nearly +20% lengthening at the posterior region only (shown as dark blue). Two-dimensional speckle-tracking echocardiography could identify such transmurally injured “dyskinetic scars” (a mechanodynamic myocardial property), which is critically important in ventricular restoration tactics.

#### d. Prediction of the non-functional akinetic region of the LV

Using these results, the exclusion area of non-functional myocardium for SVR was predicted preoperatively. A representative case with ICM is shown in **Fig. 1**. On the left side, late gadolinium enhancement of cardiac MRI demonstrated regional stains on the endocardium in the lateral, posterior, and infero-septal segments. On the right side, two-dimensional speckle-tracking echocardiography revealed LV torsion at the corresponding short-axis slice level seen on cardiac MRI. Severe ischemic injury and suggestions of fibrotic change (a tissue characteristic) were depicted by cardiac MRI, while end-systolic circumferential strain of speckle-tracking echocardiographic imaging detected nearly +20% lengthening at the posterior region only (shown as dark blue). Thus, two-dimensional speckle-tracking echocardiography could identify such transmurally injured “dyskinetic scars” (a

mechanodynamic myocardial property), which are critically important in ventricular restoration tactics.

### 3.2 Technical details of our three SVR procedures for ICM

Surgical resection is the oldest and simplest technique for LV aneurysm following myocardial infarction. At the end of the 1970s, SVR with patchplasty had been reported for the posterior and anterior regions of the LV<sup>27,28</sup>. In 1980s, Dor and associates established a new surgical technique with a circular patch (endoventricular circular patch plasty; EVCCP) for antero-septo-apical aneurysms<sup>29</sup>. Around the same time, Cooley reported ventricular endoaneurysmorrhaphy with an elliptical patch to allow prompt recovery and restoration of ventricular function<sup>30</sup>. As Hutchins and coworkers suggested the importance of cardiac geometry after SVR, cardiac surgeons modified their technique to obtain a postoperative elliptical shape of the LV<sup>31</sup>. Recently, we have developed new techniques of septal anterior ventricular exclusion (SAVE) for the anterior wall of the LV and a posterior restoration procedure (PRP) for the posterior wall in patients with dilated cardiomyopathy<sup>8,24</sup>. We performed SVR with three different procedures (EVCPP, SAVE, and PRP) for patients with ICM, and the details of our modified techniques are described below.

#### a. Modified endoventricular circular patch plasty (EVCPP)

The presence of an antero-septo-apical akinetic region is a good indication for EVCPP, as reported by Dor and coworkers<sup>29</sup>. At first, coronary revascularization was completely performed under blood cardioplegic cardiac arrest. Valvular surgery, including mitral, tricuspid, and aortic valves, was completed prior to EVCPP. To obtain a better surgical field of the anterior LV wall, two 1-0 silk sutures were placed at the apex (**Fig. 2A**). The antero-apical LV wall was opened in the center of the akinetic region (**Fig. 2B**). When thrombus formation was detected in the LV trabeculation, it was entirely removed. The anatomical margin of the contractile myocardium around the scar, the so-called "contractility trail", was observed through the ventriculotomy. To prevent late ventricular tachycardia or fibrillation (VT/VF), cryoablation was performed on the viable LV myocardium along the junction. To plicate the circular defect of the LV muscle, 2-0 polypropylene purse-string suture (Prolene®; Ethicon, Somerville, NJ, USA) was placed around the entire circumference of the contractility trail (**Fig. 2C**). Then, a collagen-impregnated Dacron knitted fabric (MAQUET Cardiovascular LLC, Wayne, NJ, USA) (approximately 3×4 cm) was placed over the plicated defect of the myocardium and fixed with 2-0 polypropylene running suture after deaeration of the LV (**Fig. 2D**). Finally, two felt strips were placed along the ventriculotomy on each side, and the excluded external scar was folded to reinforce the suture line with 2-0 polypropylene horizontal mattress sutures with a large needle (Matsuda-ika Kogyo, Tokyo, Japan). The line was secured by double 2-0 polypropylene over-and-over sutures from both ends (**Fig. 2E**).

#### b. Septal anterior ventricular exclusion (SAVE)

The presence of a large antero-septal akinetic region is a good indication for SAVE or the Pacopexy technique developed by Isomura et al<sup>8,12</sup>. As for EVCPP, complete coronary revascularization was first performed under blood cardioplegic arrest. Valvular surgery, including mitral, tricuspid, and aortic valves, was undertaken prior to SAVE. The aortic crossclamp was released to allow the heart to start beating, and perfusion pressure was

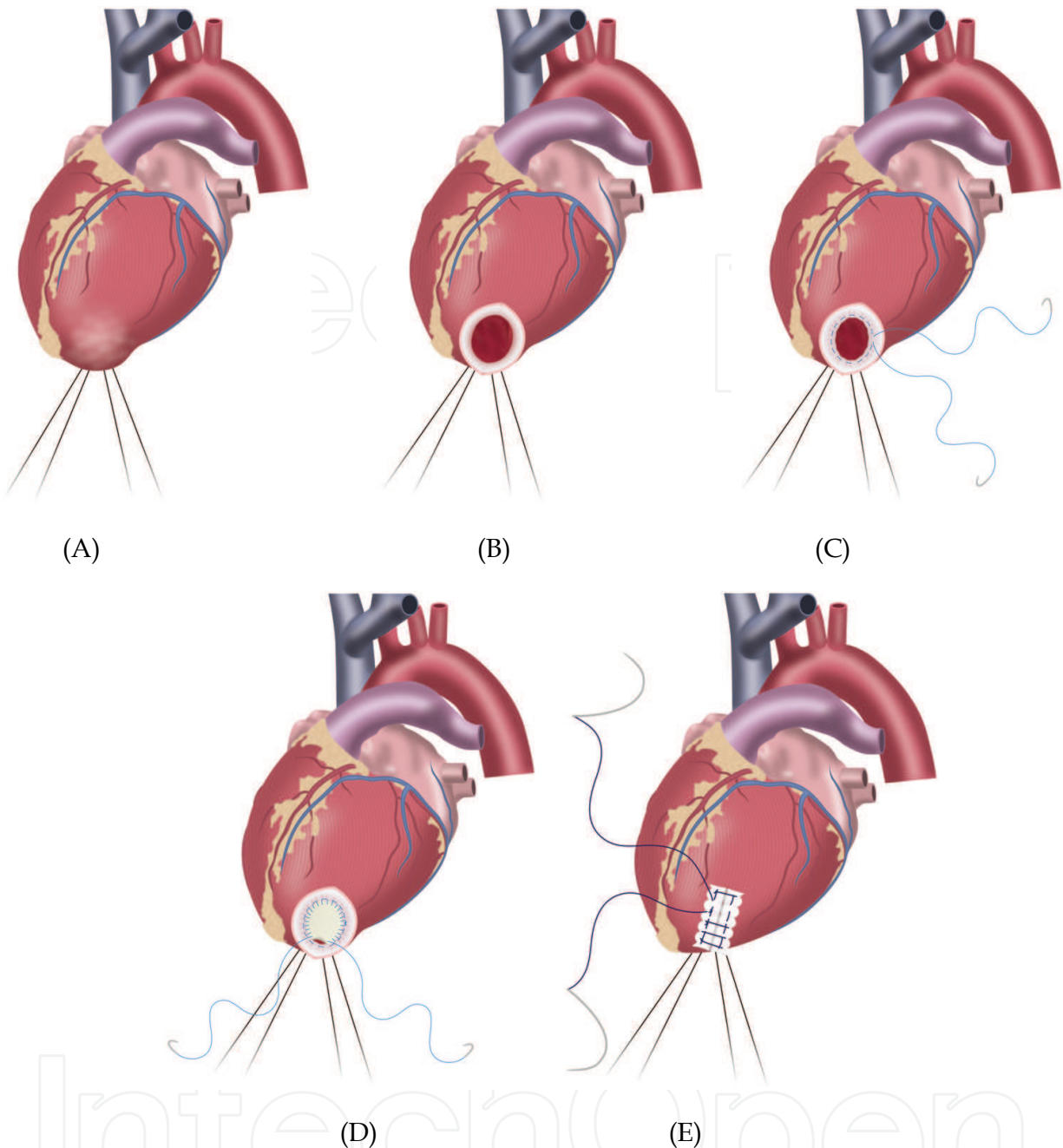


Fig. 2A. The schema shows the heart with ICM including the antero-apical akinetic region. 2B. The antero-apical LV wall is opened in the center of the region. The margin of the contractile myocardium around the scar, the so-called “contractility trail”, is observed through the ventriculotomy. 2C. To plicate the circular defect of the LV muscle, 2-0 polypropylene purse-string suture is placed around the entire circumference of the contractility trail. 2D. A collagen-impregnated Dacron knitted fabric (approximate 3×4 cm) is placed over the plicated defect of the myocardium and fixed with 2-0 polypropylene running suture after deaeration of the LV. 2E. Two felt strips are placed along the ventriculotomy on each side, and the excluded external scar is folded to reinforce the suture line with 2-0 polypropylene horizontal mattress sutures with a large needle. The line is secured by double 2-0 polypropylene over-and-over sutures from both ends.

kept >75 mmHg to ensure ongoing coronary perfusion. Thus, the SAVE operation was usually performed on the beating heart. During beating, the transitional zone between the scar and the viable myocardium was easily detected by direct manipulation of the LV muscle.

Two 1-0 silk sutures were placed at the apex to achieve a better surgical field (**Fig. 3A**). The anterior wall of the LV was opened along the left anterior descending artery from the apex toward the base (**Fig. 3B**). Cryoablation was performed on the viable LV myocardium along the incision to prevent late VT/VF. For patients with a dilated posterior wall between two papillary muscles, chordal cutting of the basal chordae and papillary muscle approximation was performed via this incision (see *Technical details of our mitral valve surgery*). Multiple 0 braided polyester horizontal mattress sutures (Ticron®; Tyco, Waltham, MA, USA) with pledgets were placed along the exclusion line of the septum, in a direction that proceeded from the apex to a septal site 1-2 cm below the aortic valve (**Fig. 3C**). A collagen-impregnated Dacron knitted fabric was trimmed to create an elliptical shape, approximately 3×8 cm, and placed along the site of the exclusion, with sutures placed 1 cm from the patch edge to leave a patch rim outside these sutures. The last two sutures were tied after deaeration of the LV (**Fig. 3D**). Finally, two felt strips were placed along the ventriculotomy on each side, and the excluded external scar was folded to reinforce the suture line with 2-0 polypropylene horizontal mattress sutures anchoring the allowance of Dacron fabric (**Fig. 3E**). The suture line was secured by double 2-0 polypropylene over-and-over sutures from both ends (**Fig. 3F**).

Some patients requiring SAVE were treated by overlapping cardiac volume reduction operations in this series<sup>32</sup>.

#### c. Posterior restoration procedure (PRP)

The posterior akinetic region of the LV was repaired with the PRP procedure developed by Isomura et al<sup>24</sup>. One of the most important operative concepts was the postoperative elliptical shape of the LV. To achieve the elliptical shape, the LV apex and bilateral papillary muscles were preserved in this operation.

As for EVCPP and SAVE, complete coronary revascularization was first performed under blood cardioplegic arrest. Valvular surgery, including mitral, tricuspid, and aortic valves, was undertaken prior to PRP. PRP was also performed in a beating heart as for the SAVE procedure. Two 1-0 silk sutures were placed at the apex. The akinetic region was opened 1 cm proximal from the apex on the posterior wall between bilateral papillary muscles (**Fig. 4A**). The incision was extended toward the base of the heart, reaching 1 cm above the mitral annulus (**Fig. 4B**). Cryoablation was performed on the viable LV myocardium along the incision to prevent late VT/VF, especially for the LV muscle between the end of the incision and the mitral annulus. Multiple 0 braided polyester horizontal mattress sutures with pledgets were placed along the exclusion line on the viable LV myocardium (**Fig. 3C**). As for the SAVE procedure, a collagen-impregnated Dacron knitted fabric was trimmed to create an elliptical shape and placed over the exclusion with a 1-cm allowance for LV closure. The last two sutures on the apex side were tied after deaeration of the LV (**Fig. 4D**). Finally, the LV was closed in a similar manner as in the SAVE procedure, and the bilateral papillary muscles were approximated during the PRP procedure (**Fig. 4E**). The line was secured by double 2-0 polypropylene over-and-over sutures from both ends (**Fig. 4F**).

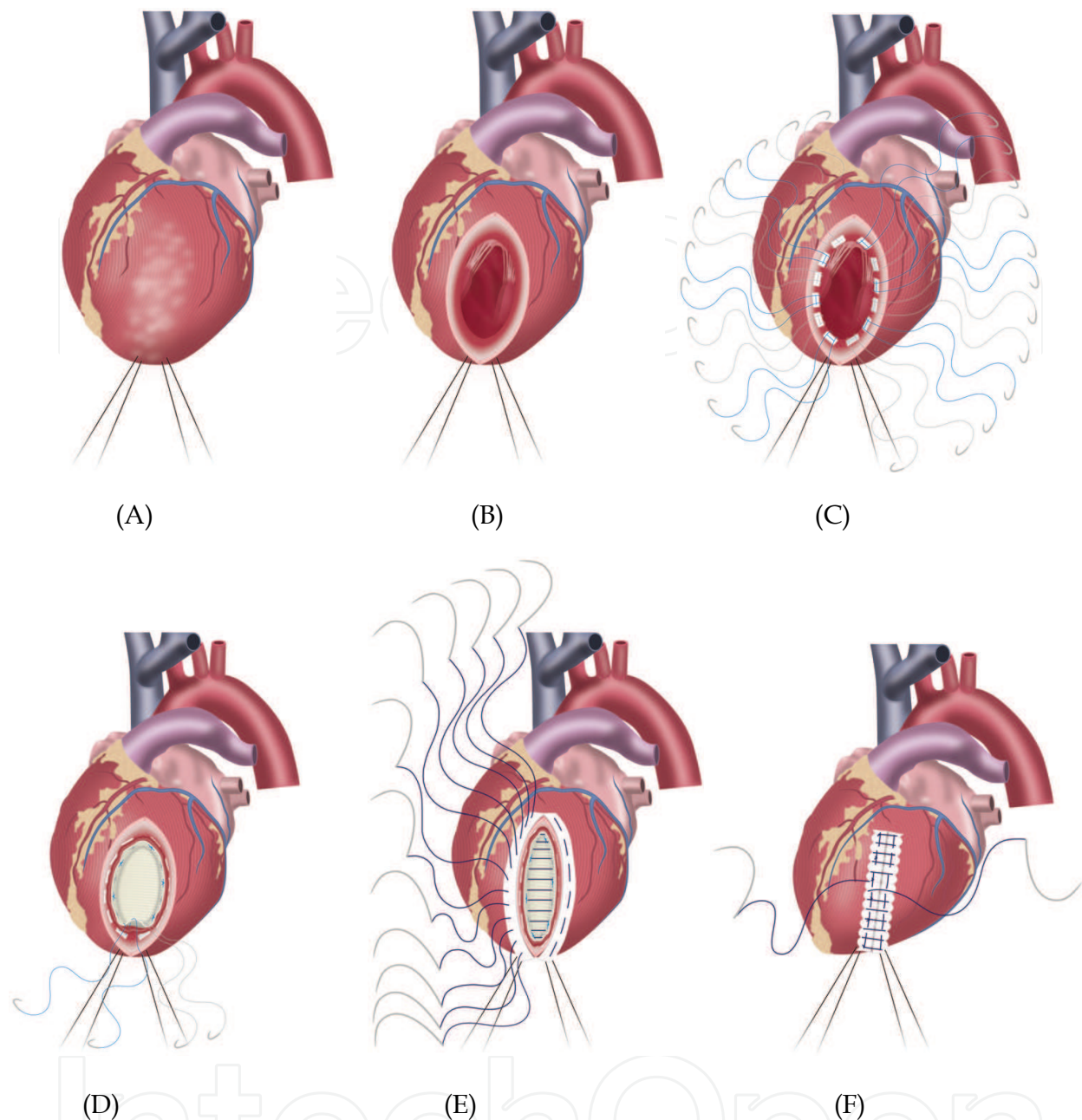


Fig. 3A. The schema shows the heart with ICM including a large antero-septal akinetic region. 3B. The antero-lateral LV wall is opened along the left descending artery from the apex toward the base. 3C. Multiple 0 braided polyester horizontal mattress sutures with pledgets are placed along the exclusion line of the septum, in a direction that proceeds from the apex to a septal site 1-2 cm below the aortic valve. 3D. A collagen-impregnated Dacron knitted fabric (approximate 3×4 cm) is placed over the plicated defect of the myocardium and fixed with 2-0 polypropylene running suture. The last two sutures on the apex side are tied after deaeration of the LV. 3E. Two felt strips are placed along the ventriculotomy on each side, and the excluded external scar is folded to reinforce the suture line with 2-0 polypropylene horizontal mattress sutures anchoring the allowance of Dacron fabric. 3F. The suture line is secured by double 2-0 polypropylene over-and-over sutures from both ends.



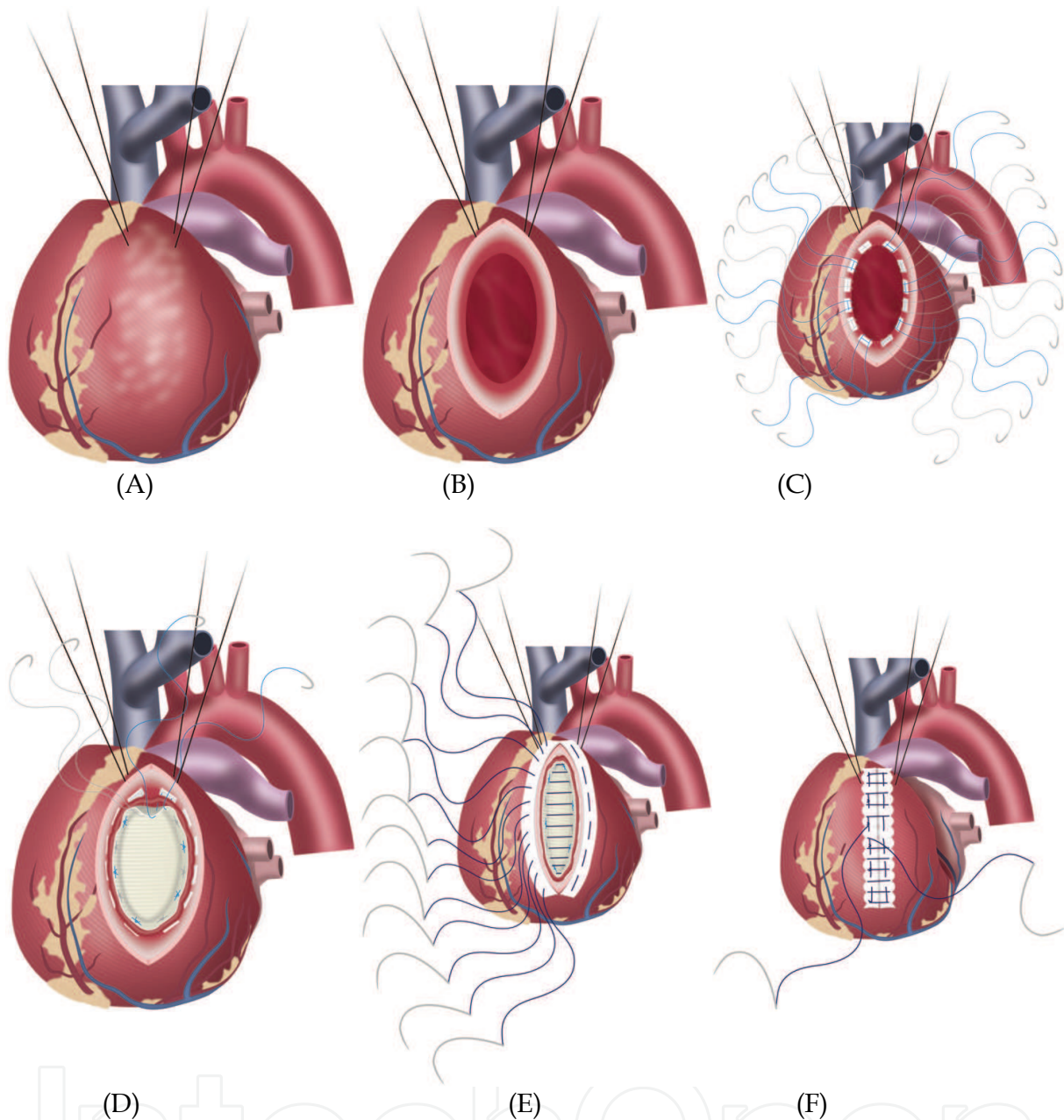


Fig. 4A. The schema shows the heart with ICM including a posterior akinetic region. 4B. The akinetic region is opened 1 cm proximal from the apex on the posterior wall between bilateral papillary muscles. The incision is extended toward the base of the heart, reaching 1 cm below the mitral annulus. 4C. Multiple 0 braided polyester horizontal mattress sutures with pledgets are placed along the exclusion line of the septum, with a direction that proceeds from the apex to a septal site 1-2 cm below the aortic valve. 4D. A collagen-impregnated Dacron knitted fabric is trimmed to create an elliptical shape and is placed over the exclusion with a 1-cm allowance for closure of the LV. The last two sutures on the apex side are tied after deaeration of the LV. 4E. Two felt strips are placed along the ventriculotomy on each side, and the excluded external scar is folded to reinforce the suture line with 2-0 polypropylene horizontal mattress sutures anchoring the allowance of Dacron fabric. The bilateral papillary muscles are approximated during the PRP procedure. 4F. The suture line is secured by double 2-0 polypropylene over-and-over sutures from both ends.

### **3.3 Anatomical relationships between the mitral leaflet and the subvalvular apparatus for ICM**

The mitral valve consists of the anterior and posterior leaflets, annulus, and chordae, supported by two papillary muscles to regulate forward blood flow from the left atrium to the LV. Under normal conditions, both mitral leaflets create a deep coaptation zone at end-systole to prevent regurgitant blood flow. However, earlier experimental and clinical studies demonstrated that restricted diastolic opening of the mitral leaflets increased valve tethering, resulting in functional MR in hearts with LV dysfunction<sup>33,34</sup>. The mechanism of functional MR can be understood in terms of an altered force balance on the mitral leaflets in systole; i.e., a combination of increased tethering forces that restrain the leaflets from closing and result from an altered three-dimensional geometry of leaflet attachments associated with LV dilatation and decreased ventricular forces that act to close the mitral leaflets. As a consequence of geometric remodeling, laterally displaced papillary muscles were detected in dilated LVs with ICM<sup>35</sup>. Although annular dilation is also one of the primary causes of functional MR, understanding of the geometric imbalance between the LV dimensions and the subvalvular apparatus is important to repair functional MR in patients with ICM<sup>36</sup>.

### **3.4 Mitral valve surgery for functional MR in patients with ICM**

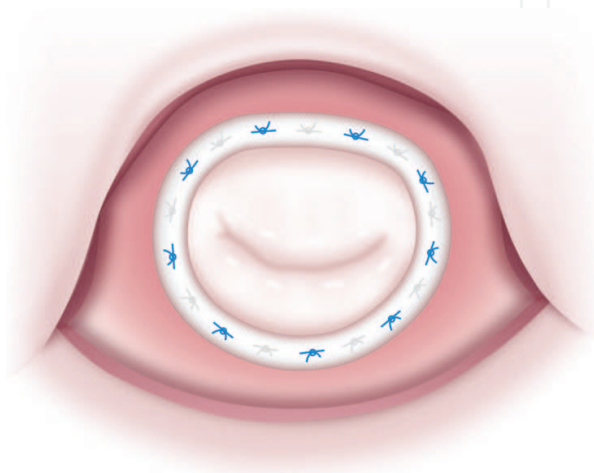
Earlier reports demonstrated that functional MR may result from dilation of the mitral annulus, laterally displaced papillary muscles, and enhanced tethering force of the valve leaflets in the hearts with dilated LV<sup>33,35-37</sup>. For these patients, functional MR was relieved by mitral valve plasty (MVP) including mitral annuloplasty (MAP) with an undersized flexible annuloplasty ring<sup>38</sup>, chordal cutting of the basal chordae<sup>39,40</sup>, papillary muscle approximation<sup>41-44</sup>, and chordal translocation<sup>45</sup>. We usually repair functional MR using MAP with a semi-rigid ring, and/or chordal cutting, and/or papillary muscle approximation. Chordal cutting and papillary muscle approximation were indicated for patients with a severely dilated LV caused by broad myocardial infarction, who would be repaired by the SAVE procedure. Details of our techniques are described below.

### **3.5 Technical details of our mitral valve surgery**

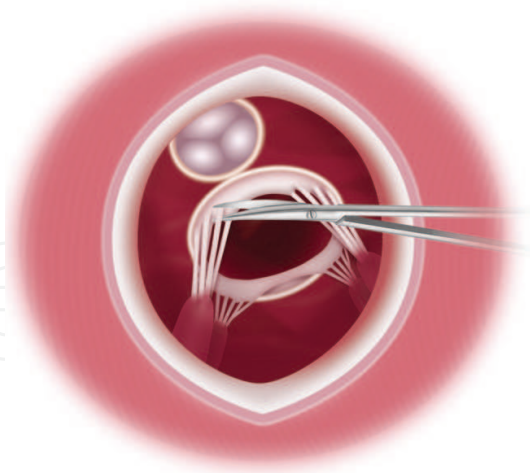
To perform MAP, the mitral valve was observed via the right-sided left atriotomy. When the MAZE procedure was required, radiofrequency ablation was performed prior to mitral valve surgery following Cox and associates<sup>46</sup>. The Cosgrove Valve Retractor System (Kapp Surgical Instrument, Inc. Cleveland, OH, USA) was used to obtain a wide surgical field around the mitral valve. First, 2-0 polyfilament braided vertical mattress sutures (Matsudai Kogyo, Tokyo, Japan) were placed on the mitral annulus. The coaptation zone of the mitral valve was directly inspected by the water test to identify the valvular morphology. Basically, the etiology of functional MR with ICM involved tethering of the subvalvular apparatus caused by a dilated LV and annular dilatation. After identification of no organic changes of the mitral leaflet, a mitral annuloplasty ring was seated on the mitral annulus (**Fig. 5A**). An undersized semi-rigid ring (Carpenter-Edwards Physio Ring®; Edwards Life Science Corporation, Irvine, CA, USA) was used for patients with central MR, while a just-sized asymmetric rigid ring (Carpentier-McCarthy-Adams IMR ETlogix annuloplasty ring®; Edwards Life Science Corporation) was used for patients with asymmetric MR from the

postero-median commissure. Chordal cutting was usually performed via the ventriculotomy during SVR, and thus the LA was closed with double 4-0 polypropylene over-and-over sutures.

For patients with a severely dilated LV requiring SAVE, chordal cutting was performed via the ventriculotomy during SVR. The basal chordae of the anterior and posterior mitral leaflets were completely cut with a pair of long scissors (**Fig. 5B**). Before suturing for SVR, two 0 braided polyester horizontal mattress sutures with pledgets (Ticron®; Tyco, Waltham, MA, USA) were placed to plicate the posterior LV wall between bilateral papillary muscles (**Fig. 5C**). They were then tied to approximate bilateral papillary muscles (**Fig. 5D**). SVR followed mitral valve surgery.



(A)



(B)

**Fig. 5A.** The mitral valve is observed via the right-sided left atriotomy. After identification of no organic changes of the mitral leaflet, a mitral annuloplasty ring is seated on the mitral annulus. **5B.** For patients with a severely dilated LV requiring the SAVE procedure, the basal chordae of the anterior and posterior mitral leaflets are completely cut with a pair of long scissors via the ventriculotomy.

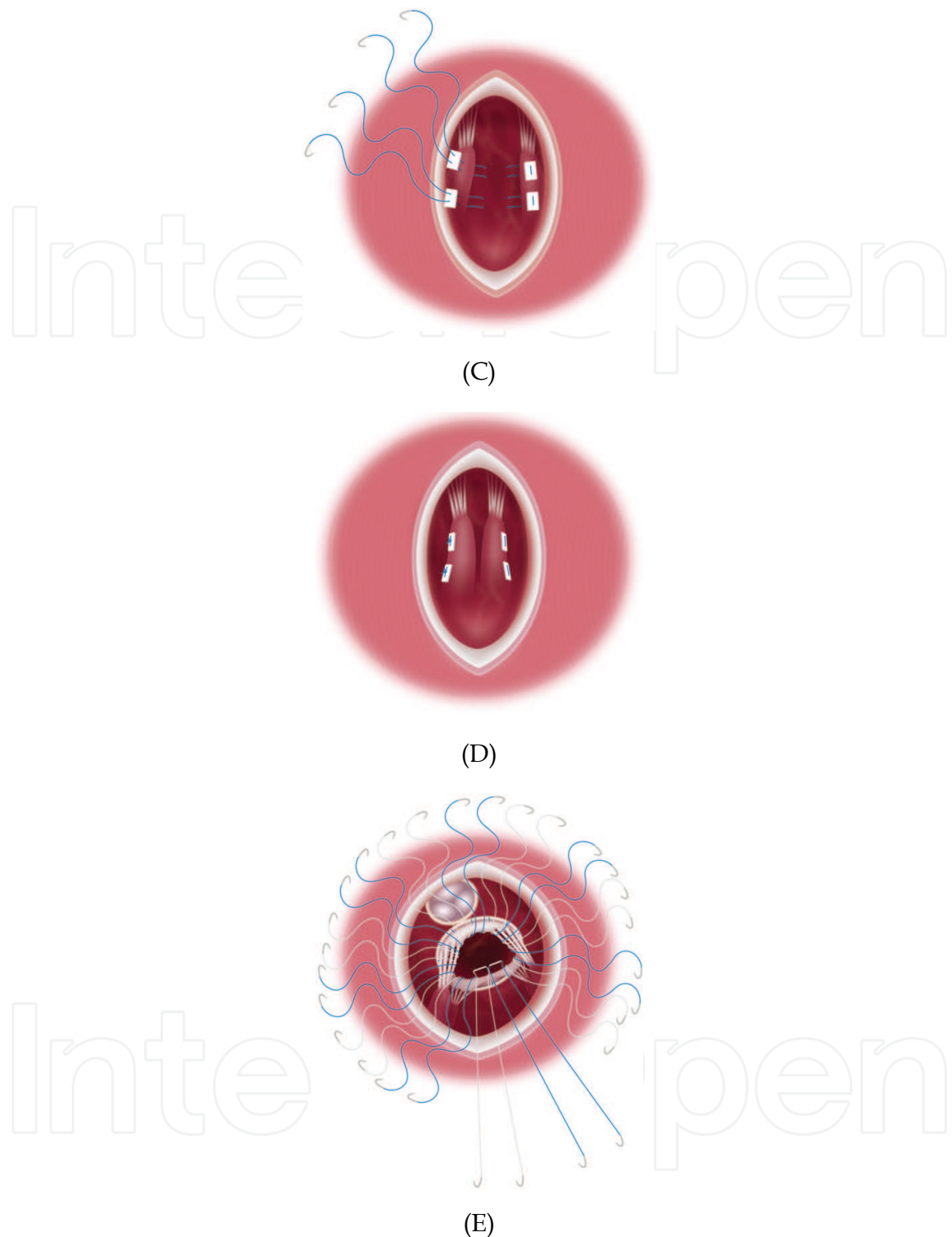


Fig. 5C. Before suturing for PRP, two 0 braided polyester horizontal mattress sutures with pledgets are placed to plicate the posterior LV wall between bilateral papillary muscles. 5D. Two sutures are tied to approximate bilateral papillary muscles. 5E. MVR is performed via the ventriculotomy during SVR in a beating heart. The mitral leaflets are preserved as much as possible to prevent LV rupture, and 2-0 polyfilament braided vertical mattress sutures are placed on the mitral annulus from the LA toward the LV. These sutures are then anchored to the mitral leaflets.

For patients requiring PRP, the bilateral papillary muscles were surgically approximated during closure of the posterior wall of the LV. Thus, the posterior wall was approximated during the usual PRP procedure.

Although MVP is a standard operation for ICM with functional MR, mitral valve replacement (MVR) is indicated for a few limited cases. In the early period of this series, MVR via the ventriculotomy was performed to reduce aortic crossclamping time. Patients with ICM and MR caused by organic valvular changes were also treated by MVR, although they were excluded in this series.

MVR was performed via the ventriculotomy during SVR in a beating heart. The ascending aorta was declamped after closure of the LV, and the LV was opened in the akinetic region. The mitral leaflets were preserved as much as possible to prevent LV rupture, and 2-0 polyfilament braided vertical mattress sutures were placed on the mitral annulus from the LA toward the LV. These sutures were then anchored to the mitral leaflets. A prosthetic mitral valve was seated in the infravalvular position (**Fig. 5E**).

### 3.6 Overview of the operative procedure

#### a. Preparation for SVR and mitral valve surgery

Under general cardiac anesthesia and monitoring, the chest was entered via median sternotomy. CPB was installed via the ascending aorta with bicaval drainage under generalized heparinization. For patients requiring coronary artery bypass grafting (CABG), all anastomoses were completed prior to opening the LA. An LA vent tube was introduced via the right upper pulmonary vein (PV) to obtain a bloodless surgical field. When the MAZE procedure was required, left PV isolation was performed with a radiofrequency ablation system (AtriCure, Inc, West Chester, OH, USA). Under mild hypothermia, the ascending aorta was crossclamped. Antegrade tepid blood cardioplegia was delivered to obtain cardioplegic cardiac arrest. For maintenance, retrograde tepid blood cardioplegia was infused every 20 to 30 minutes.

#### b. MAP via the right-sided left atriotomy

MAP was performed via the right-sided left atriotomy. Details of the technique were described above. The LA was closed in two layers.

Aortic valve replacement was performed via the aortotomy prior to SVR, when it was required. Tricuspid valve surgery was also performed via the right atriotomy when it was necessary.

#### c. SVR and other mitral procedures via the ventriculotomy

After completion of MAP, the akinetic scar was opened to perform SVR and other mitral procedures via the LV. Selection of SVR depended on the location of the scar: the antero-septo-apical region for EVCCP, a broad antero-septal region for SAVE, and the posterior region for PRP. First, chordal cutting of both mitral leaflets was performed when it was indicated for patients requiring SAVE. Details of the technique were described above.

Secondly, papillary muscle approximation was performed for patients with a severely dilated LV requiring SAVE. The technical details were described above. For patients requiring PRP, the incision of the posterior wall was placed just between both papillary muscles, resulting in papillary muscle approximation by usual LV closure.

Finally, SVR was performed after completion of other mitral procedures. The details of the procedure were described above.

#### d. Supplemental procedures

For patients with LV dyssynchrony or the inevitable cases with transection of a previously implanted LV lead during SVR, an epicardial permanent LV lead was placed on the lateral wall for cardiac resynchronization therapy (CRT) or CRT defibrillator (CRT-D)<sup>47</sup>. For the extremely severe cases with out-of-date generators for CRT or CRT-D, a new generator was upgraded during the operation.

### 3.7 Statistical analysis

The results are expressed as means±SEM. An analysis was performed using the paired or unpaired Student's *t*-test to compare between before and after SVR, respectively. The criterion for statistical significance was set at a value of  $P<0.05$ .

## 4. Results

### 1. Operative procedures

In 88 patients with ICM and MR, SVR was performed with three different procedures: EVCPP in 25 patients (28%), SAVE in 50 patients (57%) and PRP in 13 patients (15%). Two cases with antero-septal scars repaired by an overlapping cardiac volume reduction operation had a SAVE procedure. Mitral valve surgery was performed with MAP in 78 patients (89%) and MVR in 10 patients (11%). Of a total of 78 patients repaired with MAP, an under-sized Carpentier-Edwards Physio Ring was used in 72 patients (92%), and a just-sized Carpentier-McCarthy-Adams IMR ETlogix annuloplasty ring was used in 6 patients (8%). Of a total of 46 cases repaired with SAVE plus MAP, chordal cutting was required in 10 patients (22%), and papillary muscle approximation was required in 16 patients (35%). In the early period of this series, 10 patients were treated by MVR with the Carpentier-Edwards pericardial bioprosthesis (Edwards Life Science Corporation). Detailed combinations of SVR and mitral valve surgery are summarized in **Table 1**.

		ICM with MR (n=88)			
			EVCPP (n=25)	SAVE (n=50)	PRP (n=13)
MVP (n=78)	Annuloplasty	78 (100%)	23	46	9
	Chordal cutting	10 (11%)	0	10	0
	Papillary muscle approximation	25 (28%)	0	16	9
MVR (n=10)		10	2	4	4

ICM, ischemic cardiomyopathy; MR, mitral regurgitation; EVCPP, endoventricular circular patch plasty; SAVE, septal anterior ventricular exclusion; PRP, posterior restoration procedure; MVP, mitral valve plasty; MVR, mitral valve replacement

Table 1. Surgical Ventricular Restoration and Mitral Valve Surgery.

Of the 88 patients with ICM and functional MR, concomitant procedures included CABG in 63 (72%), tricuspid valve surgery in 30 (34%), aortic valve surgery in 4 (5%), and the MAZE procedure in 7 (8%). The number of grafts for patients requiring CABG was  $2.0\pm 1.4$ /patient.

Tricuspid annuloplasty was performed with the Carpentier-Edwards classic annuloplasty ring (Edwards Life Science Corporation) in 13 patients, the Edwards MC3 annuloplasty ring (Edwards Life Science Corporation) in 9 patients, the Cosgrove-Edwards annuloplasty system (Edwards Life Science Corporation) in 3 patients, the St. Jude Medical Tailor flexible band (St. Jude Medical, Inc. St. Paul, MN, USA) in 2 patients, and the DeVega technique in 3 patients. Aortic valve replacement was performed with the Carpentier-Edwards pericardial bioprosthesis (Edwards Life Science Corporation) in 4 patients (5%). Intra- and post-operative CRT or CRT-D was required in 26 patients (30%).

## 2. Early surgical results

Aortic crossclamping and CPB times are shown in **Table 2**. IABP was preoperatively introduced in 2 patients (2%) requiring the SAVE procedure, and 20 patients (23%) required postoperative IABP (6 for EVCPP, 10 for SAVE, and 4 for PRP). Two patients repaired by the SAVE procedure required a left ventricular assist system and percutaneous cardiopulmonary support after the operation.

	ICM with MR (n=88)			
		EVCPP (n=25)	SAVE (n=50)	PRP (n=13)
ACC time (min)	71 ± 10	72 ± 10	66 ± 35	97 ± 42
CPB time (min)	149 ± 29	134 ± 29	158 ± 68	154 ± 36

ACC, aortic crossclamping; CPB, cardiopulmonary bypass; ICM, ischemic cardiomyopathy; MR, mitral regurgitation; EVCPP, endoventricular circular patch plasty; SAVE, septal anterior ventricular exclusion; PRP, posterior restoration procedure

Table 2. ACC and CPB Time. (Hirota et al.)

Overall hospital mortality was 13% (11/88), with 9 patients in the SAVE group. Hospital mortalities of elective and emergent operations were 9% and 29%, respectively. The most frequent morbidity was non-sustained and sustained VT/VF (17/88; 19%). Details of hospital mortality and morbidity are shown in **Table 3**.

Geometric and hemodynamic parameters are summarized in **Table 4**. Both diastolic and systolic LV volumes (LVEDVI and LVESVI) were significantly decreased with each procedure ( $p < 0.05$ ). LVEDVI and LVESVI were the largest with SAVE (LVEDVI: EVCPP 166 ± 46 ml/m<sup>2</sup>, SAVE 185 ± 53 ml/m<sup>2</sup>, PRP 154 ± 48 ml/m<sup>2</sup>; LVESVI: EVCPP 129 ± 44 ml/m<sup>2</sup>, SAVE 149 ± 49 ml/m<sup>2</sup>, PRP 117 ± 50 ml/m<sup>2</sup>). As an index of the extent of volume reduction, the volume reduction rate (reduction volume by SVR/preoperative LV volume × 100 [%]) was calculated. The volume reduction rates of LVEDV and LVESV were similar (LVEDV: EVCPP 27%, SAVE 22%, PRP 26%; LVESV: EVCPP 19%, SAVE 21%, PRP 26%). EF and peak pulmonary artery pressure were not significantly improved with any procedure. The severity of functional MR was less after each procedure. The majority of moderate or severe MR was improved to none or trivial MR (**Fig. 6**). NYHA functional class also improved with each procedure, and of all surviving patients in classes III and IV, 78% improved to class I or II (**Fig. 7**).

ICM with MR (n=88)							
		EVCPP (n=25)		SAVE (n=50)		PRP (n=13)	
		Elective	Emergent	Elective	Emergent	Elective	Emergent
<b>Hospital Mortality</b>	<b>11 (13%)</b>	2	0	5	4	0	0
LOS	8	1	0	4	3	0	0
Sepsis	1	0	0	1	0	0	0
Gastrointestinal complication	1	0	0	0	1	0	0
Ventricular tachycardia	1	1	0	0	0	0	0
<b>Morbidity</b>							
Ventricular tachycardia/fibrillation	17 (19%)	3	1	10	1	2	0
Postoperative hemorrhage	3	2	0	0	1	0	0
Cerebrovascular accident	1	0	0	1	0	0	0
Gastrointestinal complication	1	0	0	0	1	0	0

ICM, ischemic cardiomyopathy; MR, mitral regurgitation; EVCPP, endoventricular circular patch plasty; SAVE, septal anterior ventricular exclusion; PRP, posterior restoration procedure; LOS, low output syndrome

Table 3. Hospital Mortality and Morbidity.

ICM with MR (n=88)								
	EVCPP (n=25)		SAVE (n=50)		PRP (n=13)			
	Operation		Operation		Operation		Operation	
	Before	After	Before	After	Before	After	Before	After
LVDd (mm)	69 ± 9	62 ± 9*	67 ± 7	64 ± 8*	69 ± 10	62 ± 9*	71 ± 9	58 ± 9*
LVEDVI (mm/m <sup>2</sup> )	172 ± 51	130 ± 44*	166 ± 46	122 ± 47*	185 ± 53	145 ± 42*	154 ± 48	114 ± 56*
Volume reduction rate (%)				27%		22%		26%
LVESVI (mm/m <sup>2</sup> )	140 ± 50	104 ± 42*	129 ± 44	104 ± 37*	149 ± 49	118 ± 40*	117 ± 50	87 ± 54*
Volume reduction rate(%)				19%		21%		26%
EF (%)	19 ± 6	19 ± 8	19 ± 6	19 ± 10	19 ± 6	19 ± 6	22 ± 7	21 ± 9
Peak PAP (mmHg)	39 ± 17	36 ± 14	44 ± 18	32 ± 12	39 ± 16	37 ± 15	33 ± 18	31 ± 11

ICM, ischemic cardiomyopathy; MR, mitral regurgitation; EVCPP, endoventricular circular patch plasty; SAVE, septal anterior ventricular exclusion; PRP, posterior restoration procedure; LVDd, left ventricular end-diastolic diameter; LVEDVI, left ventricular end-diastolic volume index; LVESVI, left ventricular end-systolic volume index; EF, ejection fraction; PAP, pulmonary artery pressure; Volume reduction rate is calculated as reduction volume/preoperative left ventricular volume × 100 [%] ; \*P<0.05 vs. before, Values are expressed as means ± SEM.

Table 4. Geometric and Hemodynamic Parameters.



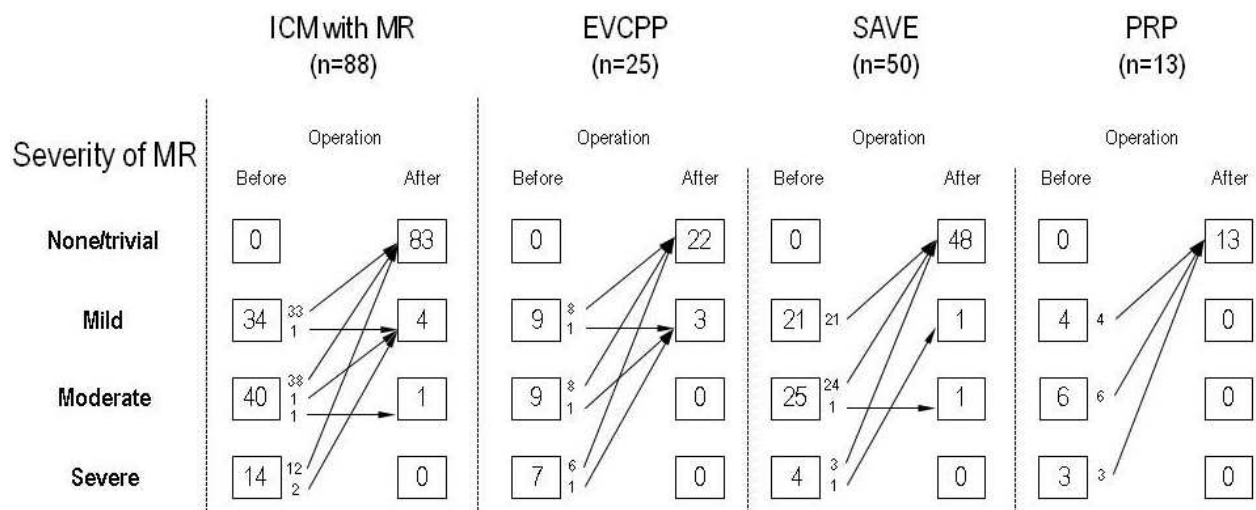


Fig. 6. The surgical effects on mitral regurgitation (MR) in patients with ischemic cardiomyopathy (ICM). In a total of 88 patients, the severity of MR was decreased after the operation. The similar effect was detected in three different procedures including endoventricular circular patch plasty (EVCCP), septal anterior ventricular exclusion (SAVE), and the posterior restoration procedure (PRP).

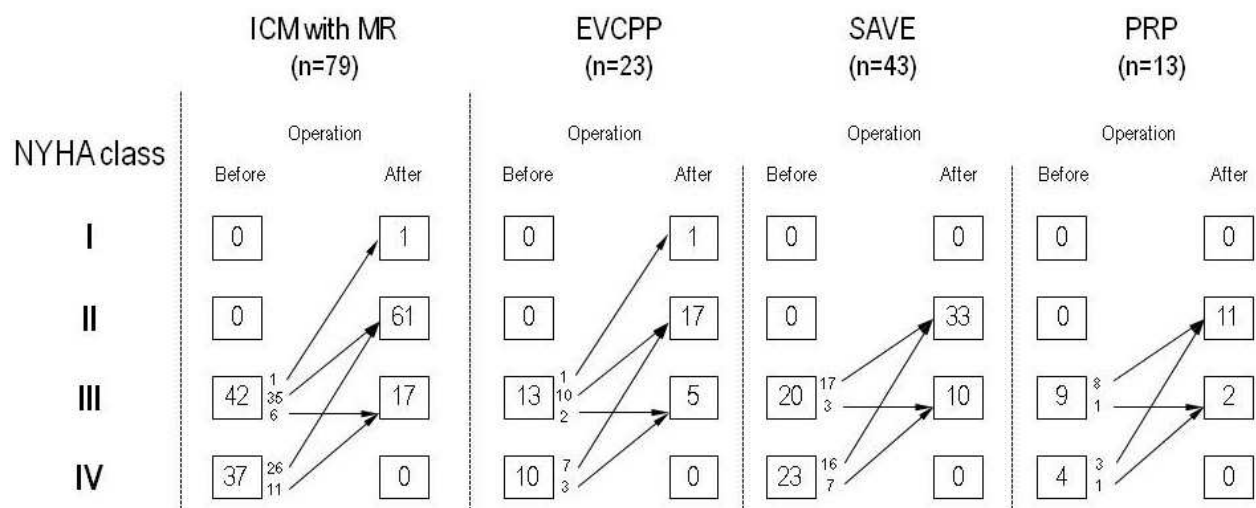


Fig. 7. The surgical effects on the New York Heart Association (NYHA) functional class in patients with ischemic cardiomyopathy (ICM) and mitral regurgitation (MR). In a total of 79 survived patients, the functional class was improved after the operation. The similar effect was detected in three different procedures including endoventricular circular patch plasty (EVCCP), septal anterior ventricular exclusion (SAVE), and the posterior restoration procedure (PRP).

### 3. Mid- to long-term surgical results

Mid- to long-term survival rates of elective operations were estimated by Kaplan-Meier analysis (Fig. 8). In this series, 1-year and 5-year overall survival rates were 84% (EVCCP 81%; SAVE 79%; PRP 100%) and 66% (EVCCP 50%; SAVE 66%; PRP 67%), respectively.

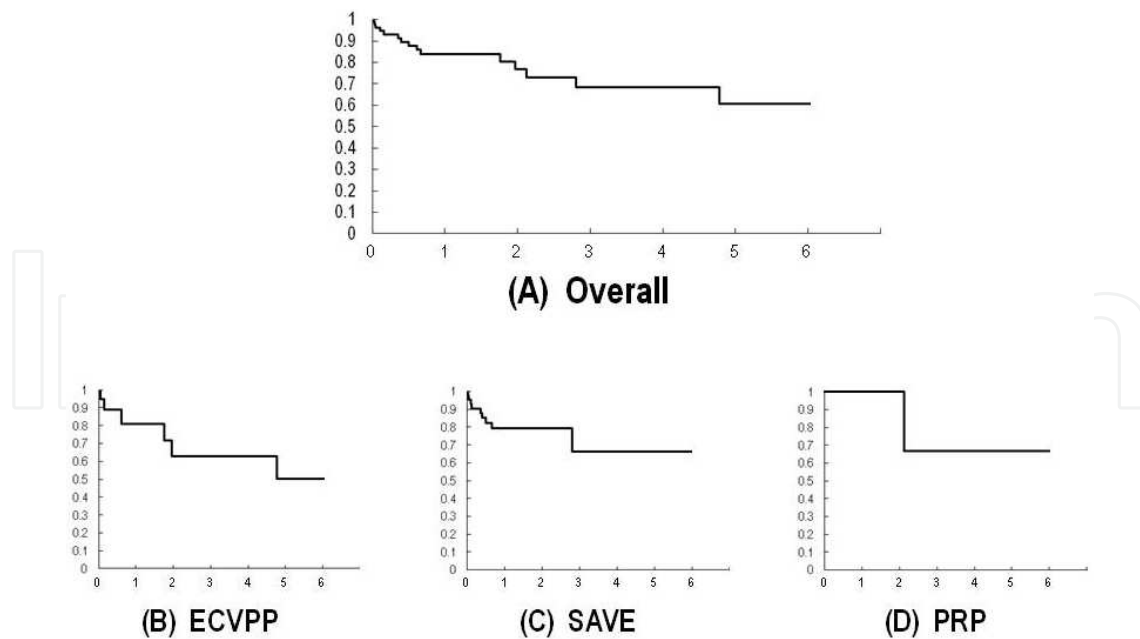


Fig. 8. Kaplan-Meier survival curves in patients with ischemic cardiomyopathy (ICM) and mitral regurgitation (MR). (A) In a total of 88 patients, overall survival repaired by the three different procedures including endoventricular circular patch plasty (EVCCP), septal anterior ventricular exclusion (SAVE), and the posterior restoration procedure (PRP). (B) Survival curve in patients repaired by EVCCP. (C) Survival curve in patients repaired by SAVE. (D) Survival curve in patients repaired by PRP.

		Papillary muscle approximation (-)		Papillary muscle approximation (+)	
		(N=34)		(N=16)	
		Operation		Operation	
Severity of MR	None/trivial	Before: 0	After: 16	Before: 0	After: 40
	Mild	Before: 8	After: 0	Before: 15	After: 1
	Moderate	Before: 7	After: 0	Before: 18	After: 1
	Severe	Before: 1	After: 0	Before: 3	After: 0
LV volume	LVDd (mm)	68 ± 10	62 ± 9*	70 ± 11	65 ± 10*
	LVEDVI (mm/m <sup>2</sup> ) Volume reduction rate (%)	172 ± 49	140 ± 41* 19%	207 ± 58	148 ± 45* 29%
	LVESVI (mm/m <sup>2</sup> ) Volume reduction rate (%)	141 ± 48	115 ± 39* 18%	174 ± 56	128 ± 44* 26%

Fig. 9. The surgical effects of papillary muscle approximation on mitral regurgitation (MR) and left ventricular (LV) volume in patients repaired by the SAVE procedure and ring annuloplasty. In a total of 50 patients, the severity of MR was decreased irrespective of papillary muscle approximation. LV volumetric indices including LV end-diastolic diameter (LVDd), LV end-diastolic volume index (LVEDVI) and LV end-systolic volume index (LVESVI) were also decreased irrespective of papillary muscle approximation. However, the volume reduction rate was much smaller in patients repaired by concomitant papillary muscle approximation.

#### 4. Effects of papillary muscle approximation in the SAVE procedure

Of the 50 patients treated with the SAVE procedure, 16 underwent papillary muscle approximation. To illustrate the effects of papillary muscle approximation, dimensional parameters and severity of MR are summarized in **Fig. 9**. Preoperative LVESVI was greater in patients repaired by SAVE and papillary muscle approximation than in patients repaired by SAVE alone ( $174 \pm 56$  vs.  $141 \pm 48$  ml/m<sup>2</sup>), but the difference was not significant. The volume reduction rate was also increased by additional papillary muscle approximation (26% vs. 19%). Irrespective of papillary muscle approximation, the severity of MR was improved after SAVE and mitral ring annuloplasty.

### 5. Discussion

We have reported the results of our surgical treatment of severe patients with ICM and functional MR and described the details of our surgical strategy. Three kinds of SVR technique effectively reduced LV dimension and changed the spherical shape of the LV into an elliptical shape. Concomitant mitral valve surgery decreased the severity of MR during SVR. This combined surgery would contribute to better surgical outcomes for these patients. The final goal of SVR for ICM with functional MR is re-establishment of the geometric balance of the remodeled LV to increase the forward flow by obtaining concentric contraction and decreasing the extent of MR. We detected the akinetic region of the LV with various techniques and excluded it with three kinds of SVR based on the location of the region. Subsequently, the contractile myocardium was connected by the elliptical patch placed on the "contractility trail". Simultaneously, for patients with a dilated posterior LV wall between two papillary muscles, it was approximated during SVR to restore subvalvular geometry beneath the mitral valve. Although there is no gold standard technique for patients with ICM and functional MR, our combined surgery appears to achieve the final goal at this moment.

For patients with ischemic heart disease, SVR has yielded beneficial short-term effects on functional status, exercise performance, long-term results, and quality of life<sup>48,49</sup>. However, concomitant SVR is still controversial during CABG for these patients<sup>48,49,50</sup>. Recently, the Surgical Treatment for Ischemic Heart Failure (STICH) trial addressed this question and demonstrated that anatomical change by SVR was not associated with a greater improvement in symptoms or exercise tolerance or with a reduction in the rate of death or hospitalization for cardiac causes<sup>50</sup>. Patient selection issues and hemodynamic effects of LV volume reduction have been proposed to explain these contradictory results<sup>50</sup>. Thus, it would be very difficult to conclude anything about the efficacies associated with SVR, even though a large, multicenter, randomized trial such as STICH has been done. Especially for a small number of patients with ICM and functional MR, the same would be true.

More recently, we have suggested the effectiveness of SVR for patients with ICM<sup>51</sup>. According to our results, SVR is most effective when a >33% volume reduction rate achieves an LVESVI of <90 ml/m<sup>2</sup>. No long-term benefits occur when SVR induces an LV volume reduction of <15%, leaving a residual LVESVI >90 ml/m<sup>2</sup>. Although the results also contradict the STICH trial findings, long-term prognosis in ICM would be determined by the relationships between accurate methods for measuring ventricular volume and the extent of SVR volume reduction.

Due to the diverse patient population, it is very difficult to compare the surgical outcomes among clinical studies and trials. Although details of patients' background were

disregarded, the cumulative survival rate was assessed by a systematic review of the literature associated with SVR in ischemic heart disease<sup>48</sup>). According to the review, the weighted average early mortality (defined as in-hospital or 30-day mortality) was 6.9%, and the cumulative 1-year and 5-year survivals were 88.5% and 71.5%, respectively. Although our surgical outcome did not reach the cumulative value, the extent of LV dysfunction with coexisting MR secondary to ischemia was much more severe in our series. More than 50% of patients had a large antero-septal akinetic region of the LV requiring the SAVE procedure, and all of them were classified as NYHA functional class III and IV. In fact, the remodeled hearts presented with severe LV dysfunction (EF <20%) with a dilated LV (LVESVI > 140 ml/m<sup>2</sup>). Moreover, more than half of the patients had concomitant severe MR (grade III and IV) in the present series. Earlier clinical reports demonstrated that the mortality risk is related to the degree of functional MR in patients with ICM<sup>52,53</sup>). Thus, our early and late surgical results would be acceptable in patients with such severe backgrounds.

Although SVR improved cardiac function and functional status for patients with ICM, it was reported that potential determinants of hospital mortality included preoperative advanced heart failure status, postoperative large LV volume (LVESVI > 60 ml/m<sup>2</sup>, LVESV > 80 ml), coexisting MR, and need for mitral valve surgery<sup>53,54</sup>). Many potential risks were involved in this series, and baseline LVESV would be much larger in a patient population with ICM and functional MR. In the present series, preoperative LVESVI (140±50 ml/m<sup>2</sup>) was larger than in other reports, and thus, postoperative LVESVI (104±42 ml/m<sup>2</sup>) was not included in the smaller LV volume category with low mortality. Although more exclusions to reduce LVESV would result in better surgical results, we believe that excessive exclusions involving contractile myocardium should be avoided for such ICM patients with severely dilated LV accompanying MR. Accordingly, prediction of the exclusion area of non-functional scar or myocardium is very important to perform effective SVR for these patients.

As one of the additional surgical adjuncts, we performed papillary muscle approximation to reduce LV volume for patients with a severely dilated LV requiring the SAVE procedure. The SAVE procedure effectively excludes a broad akinetic region of the antero-septo-apical wall, and papillary muscle approximation shortens the posterior wall between both papillary muscles. Thus, these combined procedures achieve further reduction of the LVESV. Although the volume reduction rate was increased by papillary muscle approximation, the early surgical effect on functional MR was almost the same, irrespective of papillary muscle approximation. Although the long-term effect on the LV dimension has not been elucidated, it may contribute to prevention of MR due to re-dilation of the LV.

## 6. Conclusion

SVR for patients with ICM and functional MR requires various surgical combinations depending on the location of the akinetic region, ventricular size, and subvalvular morphology beneath the MV. The surgical strategy is very important to achieve better surgical outcomes for such high-risk patients.

## 7. References

- [1] Kwan J, Shiota T, Agler DA, Popovic ZB, Qin JX, Gillinov MA, Stewart WJ, Cosgrove DM, McCarthy PM, Thomas JD; Realtime three-dimensional echocardiography study. Geometric differences of the mitral apparatus between ischemic and dilated

- cardiomyopathy with significant mitral regurgitation: real-time three-dimensional echocardiography study. *Circulation*. 2003; 107: 1135-40
- [2] Dor V, Di Donata M. Ventricular remodeling in coronary artery disease. *Curr Opin Cardiol*. 1997; 12: 533-7
- [3] Gaudron P, Eilles C, Kugler I, Ertl G. Progressive left ventricular dysfunction and remodeling after myocardial infarction. Potential mechanisms and early predictors. *Circulation*. 1993; 87: 755-63
- [4] Kaul S, Spotnitz WD, Glasfeen WP, Touchstone DA. Mechanism of ischemic mitral regurgitation: an experimental evaluation. *Circulation*. 1991; 84: 2167-80
- [5] Lamas GA, Mitchell GF, Flaker GC, Smith SC Jr, Gersh BJ, Basta L, Moye L, Braunwald E, Pfeffer MA. Clinical significance of mitral regurgitation after myocardial infarction. Survival and Ventricular Enlargement Investigators. *Circulation*. 1997; 96: 827-33
- [6] Enriquez-Sarano M, Schaff HV, Frye RL. Mitral regurgitation: what causes the leakage is fundamental to the outcome of valve repair. *Circulation*. 2003; 108: 253-6
- [7] Di Mauro M, Di Giammarco G, Vitolla G, Contini M, Iaco AL, Bivona A, Weltert L, Calafiore AM. Impact of no-to-moderate mitral regurgitation on late results after isolated coronary artery bypass grafting in patients with ischemic cardiomyopathy. *Ann Thorac Surg*. 2006; 81: 2128-34
- [8] Isomura T, Horii T, Suma H, Buckberg GD; RESTORE Group. Septal anterior ventricular exclusion operation (Pacopexy) for ischemic dilated cardiomyopathy: treatment form not disease. *Eur J Cardiothorac Surg*. 2006; 29 Suppl 1: S245-50
- [9] Di Donato M, Sabatier M, Montiglio F, Maioli M, Toso A, Fantini F, Dor V. Outcome of left ventricular aneurysmectomy with patch repair in patients with severely depressed pump function. *Am J Cardiol*. 1995; 15: 557-61
- [10] Dor V, Sabatier M, Di Donato M, Montiglio F, Toso A, Maioli M. Efficacy of endoventricular patch plasty in large postinfarction akinetic scar and severe left ventricular dysfunction: comparison with a series of large dyskinetic scars. *J Thorac Cardiovasc Surg*. 1998; 116: 50-9
- [11] Di Donato M, Toso A, Maioli M, Sabatier M, Stanley AW Jr, Dor V; RESTORE group. Intermediate survival and predictors of death after surgical ventricular restoration. *Semin Thorac Cardiovasc Surg*. 2001; 13: 468-75
- [12] Athanasuleas CL, Stanley AW Jr, Buckberg GD, Dor V, Di Donato M, Blaskstone EH. Surgical anterior ventricular endocardial restoration (SAVER) in the dilated remodeled ventricle after anterior myocardial infarction. RESTORE group. Reconstructive Endoventricular Surgery, returning Torsion Original Radius Elliptical Shape to the LV. *J Am Coll Cardiol*. 2001; 37: 1199-209
- [13] Menicanti L, Di Donat M, Castelvechio S, Santambrogio C, Montericcio V, Frigiola A, Buckberg G; RESTORE group. Functional ischemic mitral regurgitation in anterior ventricular remodeling: results of surgical ventricular restoration with and without mitral repair. *Heart Fail Rev*. 2004; 9: 317-27
- [14] Kaza AK, Patel MR, Fiser SM, Long SM, Kern JA, Tribble CG, Kron IL. Ventricular reconstruction results in improved left ventricular function and amelioration of mitral insufficiency. *Ann Surg*. 2002; 235: 828-32

- [15] Dor V, Civaia F, Alexandrescu C, Montiglio F. The post-myocardial infarction scarred ventricle and congestive heart failure: the preeminence of magnetic resonance imaging for preoperative, intraoperative, and postoperative assessment. *J Thorac Cardiovasc Surg.* 2008; 136: 1405-12
- [16] Fernandez-Golfin C, De Aquistin A, Manzano MC, Bustos A, Sanchez T, Perez de Isla L, Fuentes M, Macaya C, Zamorano J. Cardiac magnetic resonance determinants of functional mitral regurgitation in ischemic and non ischemic left ventricular dysfunction. *Int J Cardiovasc Imaging.* 2011; 27: 539-46
- [17] Lang RM, Vignon P, Weinert L, Bednarz J, Korcarz C, Sandelski J, Koch R, Prater D, Mor-Avi V. Echocardiographic quantification of regional left ventricular wall motion with color kinesis. *Circulation.* 1996; 93: 1877-85
- [18] Bansal M, Jeffriess L, Leano R, Mundy J, Marwick TH. Assessment of myocardial viability at dobutamine echocardiography by deformation analysis using tissue velocity and speckle-tracking. *JACC Cardiovasc Imaging.* 2010; 3: 121-31
- [19] Fieno DS, Kim RJ, Chen EL, Lomasney JW, Klocke FJ, Judd RM. Contrast-enhanced magnetic resonance imaging of myocardium at risk: distinction between reversible and irreversible injury throughout infarct healing. *J Am Coll Cardiol.* 2000; 36: 1985-91
- [20] Isomura T, Suma H, Horii T, Sato T, Kikuchi N. Partial left ventriculectomy, ventriculoplasty or valvular surgery for idiopathic dilated cardiomyopathy – the role of intra-operative echocardiography. *Eur J Cardiothorac Surg.* 2000; 17: 239-45
- [21] Geyer H, Caracciolo G, Abe H, Wilansky S, Careri S, Gentile F, Nesser HJ, Khandheria B, Narula J, Sen Gupta PP. Assessment of myocardial mechanics using speckle tracking echocardiography: fundamentals and clinical applications. *J Am Soc Echocardiogr.* 2010; 23: 351-69; quiz 453-5
- [22] Reisner SA, Lysyansky P, Agmon Y, Mutlak D, Lessick J, Friedman Z. Global longitudinal strain: a novel index of left ventricular systolic function. *J Am Soc Echocardiogr.* 2004; 17: 630-3
- [23] Leitman M, Lysyansky P, Sidenko S, Shir V, Peleq E, Binenbaum M, Kaluski E, Krakover R, Vered Z. Two-dimensional strain – a novel software for real-time quantitative echocardiographic assessment of myocardial function. *J Am Soc Echocardiogr.* 2004; 17: 1021-9
- [24] Isomura T, Notomi Y, Hoshino J, Fukada Y, Katahira S, Kitamura A, Kondo T, Iwasaki T. Indication of posterior restoration and surgical results in patients with dilated cardiomyopathy. *Eur J Cardiothorac Surg.* 2010; 38: 171-5
- [25] Becker M, Hoffmann R, Kuhl M. Analysis of myocardial deformation based on ultrasonic pixel tracking to determine transmural strain in chronic myocardial infarction. *Eur Heart J.* 2006; 27: 2560-6
- [26] Popovic Z, Benejam B, Bian C. Speckle-tracking echocardiography correctly identifies segmental left ventricular dysfunction induced by scarring in a rat model of myocardial infarction. *Am J Physiol Heart Circ Physiol.* 2007; 292: 2809-16

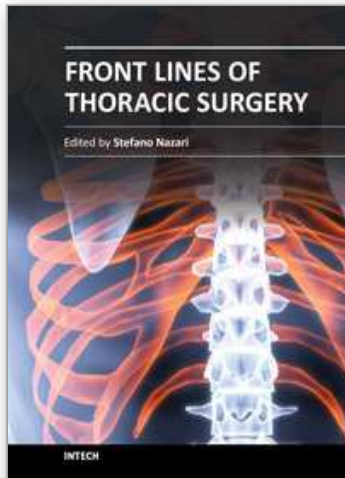
- [27] Dageatt, WM, Guyton RA, Mundth ED, Buckley MJ, McEnany MT, Gold HK, Leinbach RC, Austen WG. Surgery for post-myocardial infarct ventricular septal defect. *Ann Surg.* 1977; 186: 260-71
- [28] Levinsky L, Arani DT, Raza ST, Kohn R, Schimert G. Dacron patch enlargement of anterior wall of left ventricle after aneurysmectomy with concomitant infarctectomy. *J Thorac Cardiovasc Surg.* 1979; 77: 753-6
- [29] Dor V, Saab M, Coste P, Kornaszewska M, Montigilo F. Left ventricular aneurysm: a new surgical approach. *Thorac Cardiovasc Surg.* 1989; 37: 11-9
- [30] Cooley DA. Ventricular endoaneurysmorrhaphy: a simplified repair for extensive postinfarction aneurysm. *J Card Surg.* 1989; 4: 200-5
- [31] Hutchins GM, Brawley RK. The influence of cardiac geometry on the results of ventricular aneurysm repair. *Am J Pathol.* 1980; 99: 221-30
- [32] Matui Y, Fukada Y, Suto Y, Yamauchi H, Luo B, Miyama M, Sasaki S, Tanabe T, Yasuda K. Overlapping cardiac volume reduction operation. *J Thorac Cardiovasc Surg.* 2002; 124: 395-7
- [33] Otsuji Y, Handschumacher MD, Schwammenthal E, Jiang L, Song JK, Guerrero JL, Vlahakes GJ, Levine RA. Insights from three-dimensional echocardiography into the mechanism of functional mitral regurgitation: direct in vivo demonstration of altered leaflet tethering geometry. *Circulation.* 1997; 96: 1999-2008
- [34] Otsuji Y, Gilon D, Jiang L, He S, Leavitt M, Roy MJ, Birmingham MJ, Levine RA. Restricted diastolic opening of the mitral leaflets in patients with left ventricular dysfunction: evidence for increased valve tethering. *J Am Coll Cardiol.* 1998; 32: 398-404
- [35] Kumanohoso T, Otsuji Y, Yoshifuku S, Matsukida K, Koriyama C, Kisanuki A, Minagoe S, Levine RA, Tei C. Mechanism of higher incidence of ischemic mitral regurgitation in patients with inferior myocardial infarction: quantitative analysis of left ventricular and mitral valve geometry in 103 patients with prior myocardial infarction. *J Thorac Cardiovasc Surg.* 2003; 125: 135-43
- [36] Otsuji Y, Kumanohoso T, Yoshifuku S, Matsukida K, Koriyama C, Kisanuki A, Minagoe S, Levine RA, Tei C. Isolated annular dilation does not usually cause important functional mitral regurgitation: comparison between patients with lone atrial fibrillation and those with idiopathic or ischemic cardiomyopathy. *J Am Coll Cardiol.* 2002; 15: 1651-6
- [37] Hueb AC, Jatene FB, Moreira LF, Pomerantzeff PM, Kallas E, de Oliveria SA. Ventricular remodeling and mitral valve modifications in dilated cardiomyopathy: new insights from anatomic study. *J Thorac Cardiovasc Surg.* 2002; 124: 1216-24
- [38] Bolling SF, Pagani FD, Deeb GM, Bach DS. Intermediate-term outcome of mitral reconstruction in cardiomyopathy. *J Thorac Cardiovasc Surg.* 1998; 115: 381-8
- [39] Messas E, Guerrero JL, Handschumacher MD, Conrad C, Chow CM, Sullivan S, Yoganathan AP, Levine RA. Chordal cutting: a new therapeutic approach for ischemic mitral regurgitation. *Circulation.* 2001; 104: 1958-63

- [40] Borger MA, Murphy PM, Alam A, Fazel S, Maqanti M, Armstrong S, Rao V, David TE. Initial results of the chordal-cutting operation for ischemic mitral regurgitation. *J Thorac Cardiovasc Surg.* 2007; 133: 1483-92
- [41] Nair RU, Williams SG, Nwafor KU, Hall AS, Tan LB. Left ventricular volume reduction without ventriculectomy. *Ann Thorac Surg.* 2001; 71: 2046-9
- [42] Havss U, Tapia M, Baron F, Pouzet B, Shafy A. Papillary muscle sling: a new functional approach to mitral repair in patients with ischemic left ventricular dysfunction and functional mitral regurgitation. *Ann Thorac Surg.* 2003; 75: 809-11
- [43] Matsui Y, Suto Y, Shimura S, Fukada Y, Naito Y, Yasuda K, Sasaki S. Impact of papillary muscles approximation on the adequacy of mitral coaptation in functional mitral regurgitation due to dilated cardiomyopathy. *Ann Thorac Cardiovasc Surg.* 2005; 11: 164-71
- [44] Rama A, Prascheker L, Barreda E, Gandjbakhch I. Papillary muscle approximation for functional ischemic mitral regurgitation: *Ann Thorac Surg.* 2007; 84: 2130-1
- [45] Masuyama S, Marui A, Shimamoto T, Nonaka M, Tsukiji M, Watanabe N, Ikeda T, Yoshida K, Komeda M. Chordal translocation for ischemic mitral regurgitation may ameliorate tethering of the posterior and anterior mitral leaflets. *J Thorac Cardiovasc Surg.* 2008; 136: 868-75
- [46] Cox JL, Ad N, Palazzo T, Fitzpatrick S, Suyderhound JP, DeGroot KW, Pirovic EA, Lou HC, Duvall WZ, Kim YD. The Maze-III procedure combined with valve surgery. *Semin Thorac Cardiovasc Surg.* 2000; 12: 53-5
- [47] Lindner O, Vogt J, Kammeier A, Wielepp P, Holzinger J, Baller D, Lamp B, Hansky B, Korfer R, Horstkotte D, Burchert W. Effect of cardiac resynchronization therapy on global and regional oxygen consumption and myocardial blood flow in patients with non-ischaemic and ischaemic cardiomyopathy. *Eur Heart J.* 2005; 26: 70-6
- [48] Klein P, Bax JJ, Shaw LJ, Feringa HH, Versteegh MI, Dion RA, Klautz RJ. Early and late outcome of left ventricular reconstruction surgery in ischemic heart disease. *Eur J Cardiothorac Surg.* 2008; 34: 1149-57
- [49] Athanasuleas CL, Buckberg GD, Stanley AW, Siler W, Dor V, Di Donato M, Menicanti L, Almeida de, Oliveria S, Beyersdorf F, Kron IL, Suma H, Kouchoukos NT, Moore W, Oz MC, Fontan F, Scott ML, Accola KA; RESTORE group. *J Am Coll Cardiol.* 2004; 44: 1439-45
- [50] Jones RH, Velazquez EJ, Michler RE, Sopko G, Oh JK, O'Connor CM, Hill JA, Menicanti L, Sadowski Z, Desvigne-Nickens P, Rouleau JL, Lee KL; STICH Hypothesis 2 Investigators. Coronary bypass surgery with or without surgical ventricular reconstruction. *N Engl J Med.* 2009; 360: 1705-17
- [51] Isomura T, Hoshino J, Fukada Y, Kitamura A, Katahira S, Kondo T, Iwasaki T, Buckberg G; RESTORE Group. Volume reduction rate by surgical ventricular restoration determines late outcome in ischaemic cardiomyopathy. *Eur J Heart Fail.* 2011; 13: 423-31
- [52] Grigioni F, Enriquez-Sarano M, Zehr KJ, Bailey KR, Tajik AJ. Ischemic mitral regurgitation: long-term outcome and prognostic implications with quantitative Doppler assessment. *Circulation.* 2001; 103: 1759-64



- [53] Menicanti L, Castelvechio S, Ranucci M, Frigiola A, Santambrogio C, de Vincentiis C, Brankovic J, Di Donato M. Surgical therapy for ischemic heart failure: single-center experience with surgical anterior ventricular restoration. *J Thorac Cardiovasc Surg.* 2007; 134: 433-41
- [54] Witkowski TG, ten Brinke EA, Delgado V, Ng AC, Bertini M, Marsan NA, Ewe SH, Auger D, Yiu KH, Braun J, Klein P, Steendijk P, Versteegh MI, Klautz RJ, Bax JJ. Surgical ventricular restoration for patients with ischemic heart failure: determinants of two-year survival. *Ann Thorac Surg.* 2011; 91: 491-8

IntechOpen



## **Front Lines of Thoracic Surgery**

Edited by Dr. Stefano Nazari

ISBN 978-953-307-915-8

Hard cover, 412 pages

**Publisher** InTech

**Published online** 03, February, 2012

**Published in print edition** February, 2012

Front Lines of Thoracic Surgery collects up-to-date contributions on some of the most debated topics in today's clinical practice of cardiac, aortic, and general thoracic surgery, and anesthesia as viewed by authors personally involved in their evolution. The strong and genuine enthusiasm of the authors was clearly perceptible in all their contributions and I'm sure that will further stimulate the reader to understand their messages. Moreover, the strict adhesion of the authors' original observations and findings to the evidence base proves that facts are the best guarantee of scientific value. This is not a standard textbook where the whole discipline is organically presented, but authors' contributions are simply listed in their pertaining subclasses of Thoracic Surgery. I'm sure that this original and very promising editorial format which has and free availability at its core further increases this book's value and it will be of interest to healthcare professionals and scientists dedicated to this field.

### **How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Masanori Hirota, Shintaro Katahira, Joji Hoshino, Yasuhisa Fukada, Taichi Kondo, Takayuki Gyoten, Yuichi Notomi and Tadashi Isomura (2012). Surgical Ventricular Restoration for Ischemic Cardiomyopathy with Functional Mitral Regurgitation, Front Lines of Thoracic Surgery, Dr. Stefano Nazari (Ed.), ISBN: 978-953-307-915-8, InTech, Available from: <http://www.intechopen.com/books/front-lines-of-thoracic-surgery/surgical-ventricular-restoration-for-ischemic-cardiomyopathy-with-functional-mitral-regurgitation>

**INTECH**  
open science | open minds

### **InTech Europe**

University Campus STeP Ri  
Slavka Krautzeka 83/A  
51000 Rijeka, Croatia  
Phone: +385 (51) 770 447  
Fax: +385 (51) 686 166  
[www.intechopen.com](http://www.intechopen.com)

### **InTech China**

Unit 405, Office Block, Hotel Equatorial Shanghai  
No.65, Yan An Road (West), Shanghai, 200040, China  
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元  
Phone: +86-21-62489820  
Fax: +86-21-62489821

© 2012 The Author(s). Licensee IntechOpen. This is an open access article distributed under the terms of the [Creative Commons Attribution 3.0 License](#), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

IntechOpen

IntechOpen