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Surgical Ventricular Restoration for Ischemic Cardiomyopathy with Functional Mitral Regurgitation

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1. Introduction

Ischemic cardiomyopathy (ICM) is defined as diffuse akinesis of the ventricle after myocardial ischemia[1)]. 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)[2-5)]. Although a dilated LV with poor cardiac function is a risk by itself, coexisting functional MR worsens the prognosis of ICM[6,7)]. 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[8-12)]. 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[13,14)]. 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)[15,16] and color kinesis echocardiography[17]. Regional LV strain was assessed by speckle-tracking echocardiography under normal and dobutamine-stress conditions[18].

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[15,16]. 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[19].

b. Color kinesis echocardiography

Color kinesis is a non-invasive technology for the echocardiographic assessment of LV wall motion based on acoustic quantification[17]. 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[20]. 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[21]. 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[22,23].

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[24]. 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[25,26].

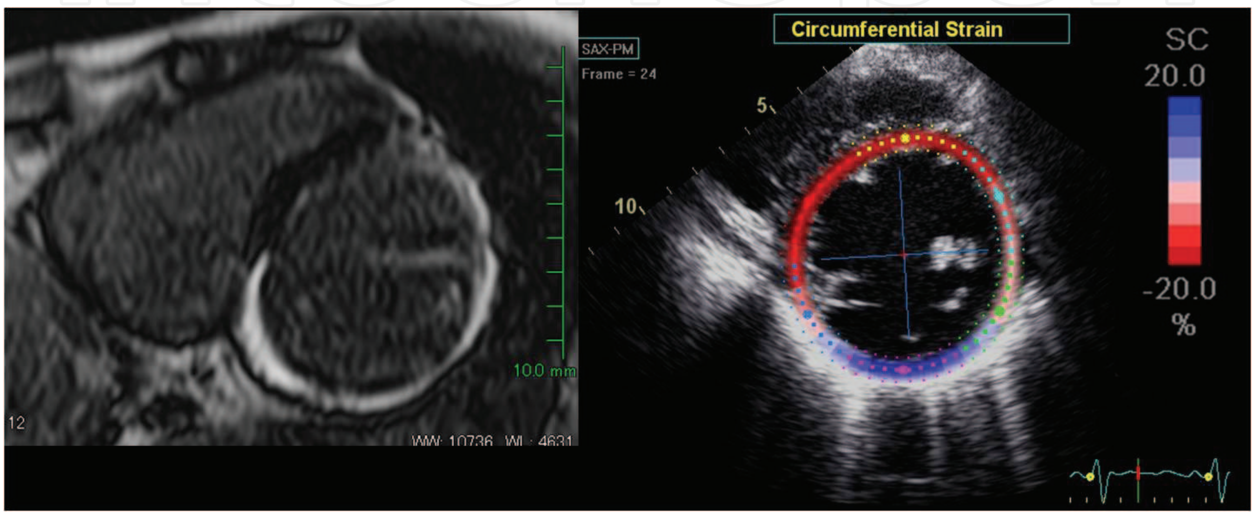


Fig. 1. Late gadolinium enhancement of cardiac magnetic resonance imaging (in the left panel) and two-dimensional speckle-tracking echocardiographic imaging (in the right panel) in a representative case with ischemic cardiomyopathy. Severe ischemic injury and a suggestion of fibrotic change (a tissue 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[27,28]. In 1980s, Dor and associates established a new surgical technique with a circular patch (endoventricular circular patch plasty; EVCCP) for antero-septo-apical aneurysms[29]. Around the same time, Cooley reported ventricular endoaneurysmorrhaphy with an elliptical patch to allow prompt recovery and restoration of ventricular function[30]. 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[31]. 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[8,24]. 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[29]. 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[8,12]. As for EVCPP, complete coronary revascularization was first preformed 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

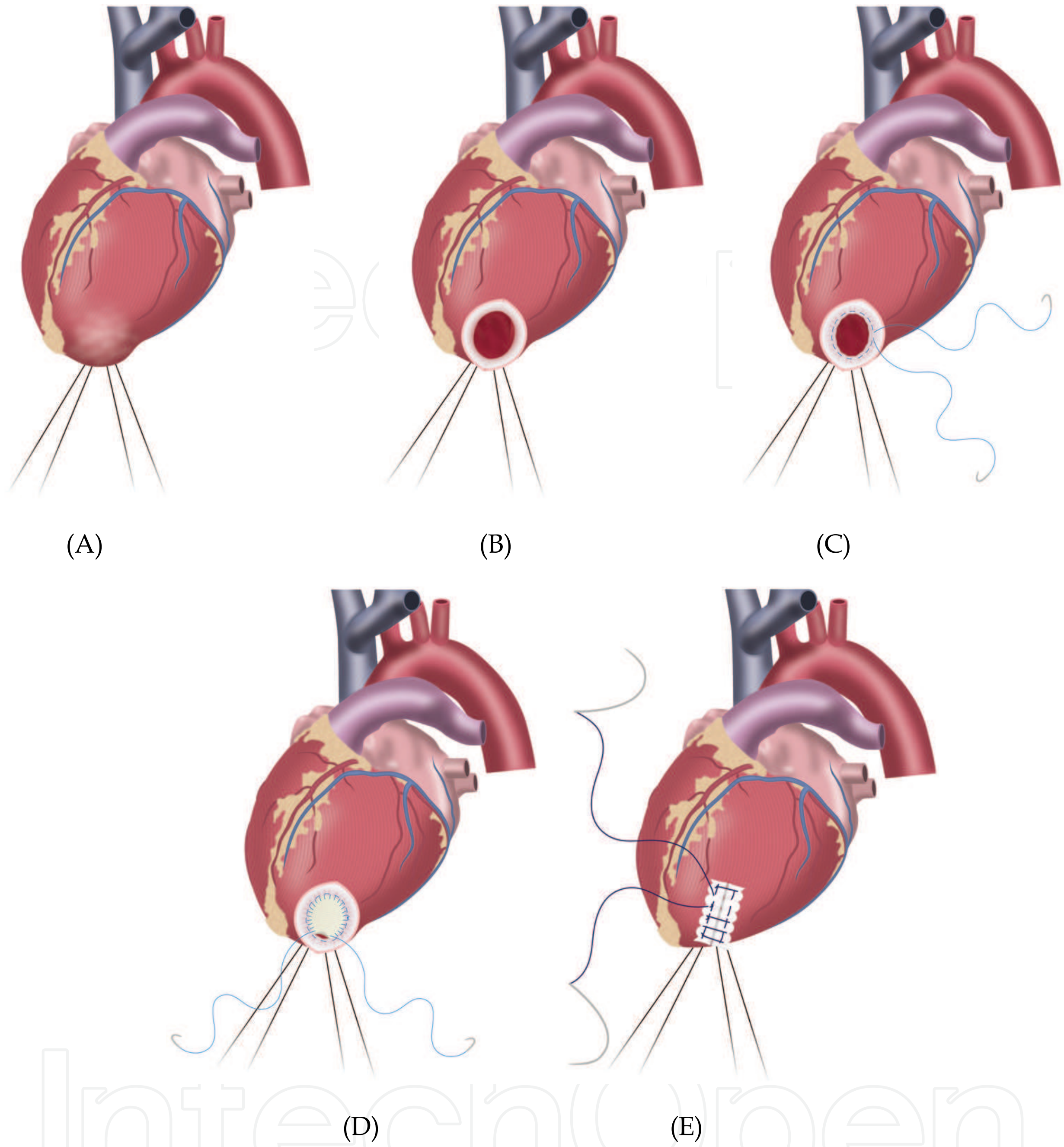


Fig. **2A**. The schema shows the heart with ICM including the antero-apical akinetic region. **2B.** The antero-apical LV wall is opened in the center of the region. The margin of the contractile myocardium around the scar, the so-called "contractility trail", is observed through the ventriculotomy. **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.

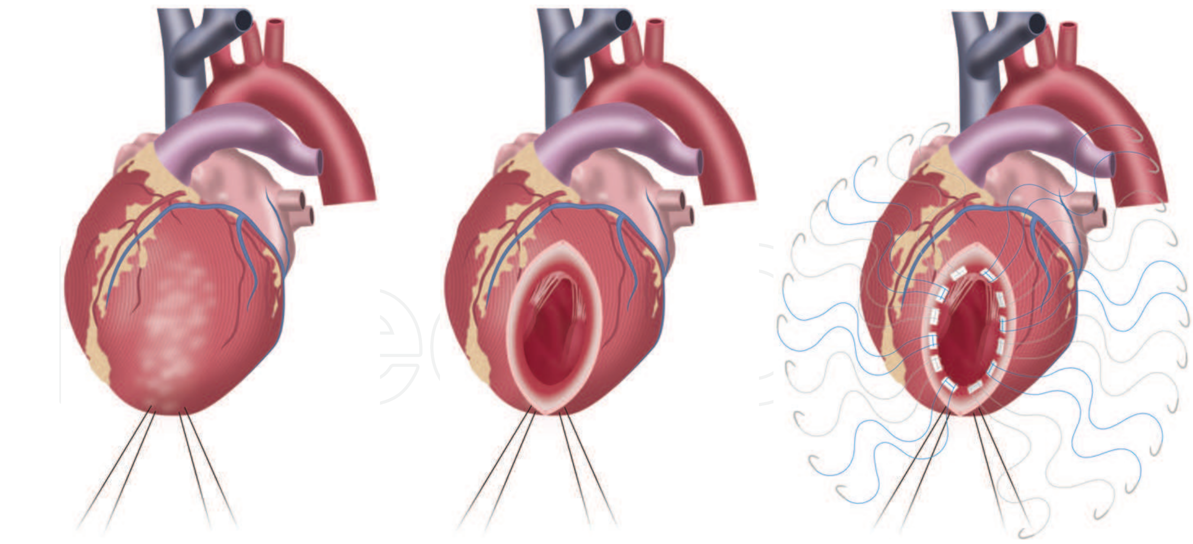
Two 1-0 silk sutures were placed at the apex to achieve a better surgical field (**Fig. 3A**). The anterior wall of the LV was opened along the left anterior descending artery from the apex toward the base (**Fig. 3B**). Cryoablation was performed on the viable LV myocardium along the incision to prevent 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[32)].

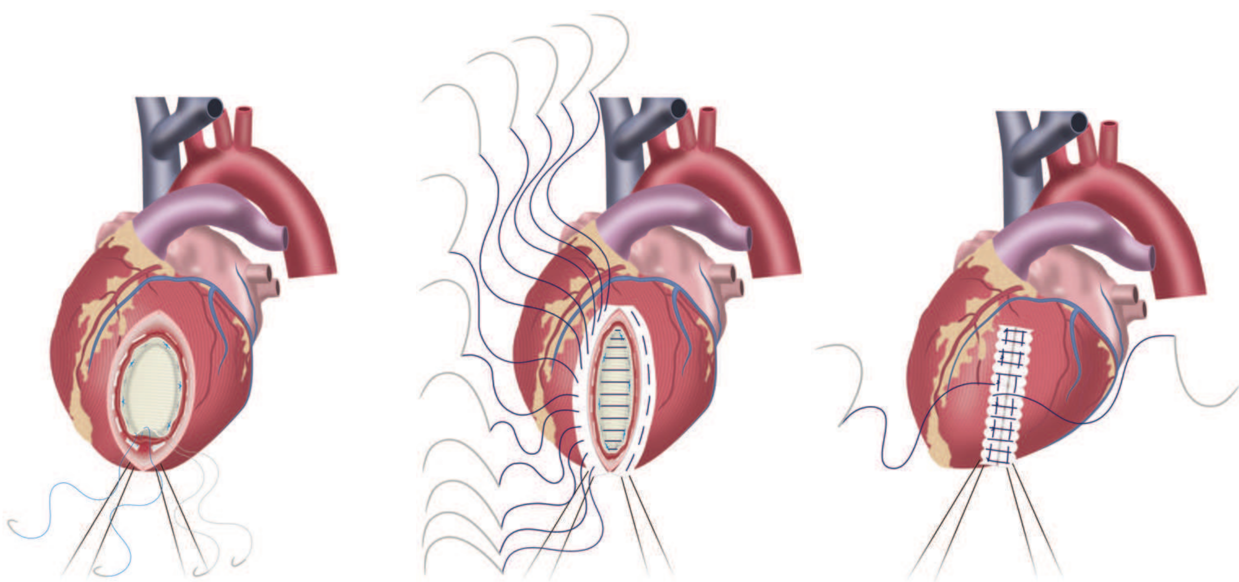
c. Posterior restoration procedure (PRP)

The posterior akinetic region of the LV was repaired with the PRP procedure developed by Isomura et al[24)]. 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 preformed 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**).



(A) (B) (C)



(D) (E) (F)

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.

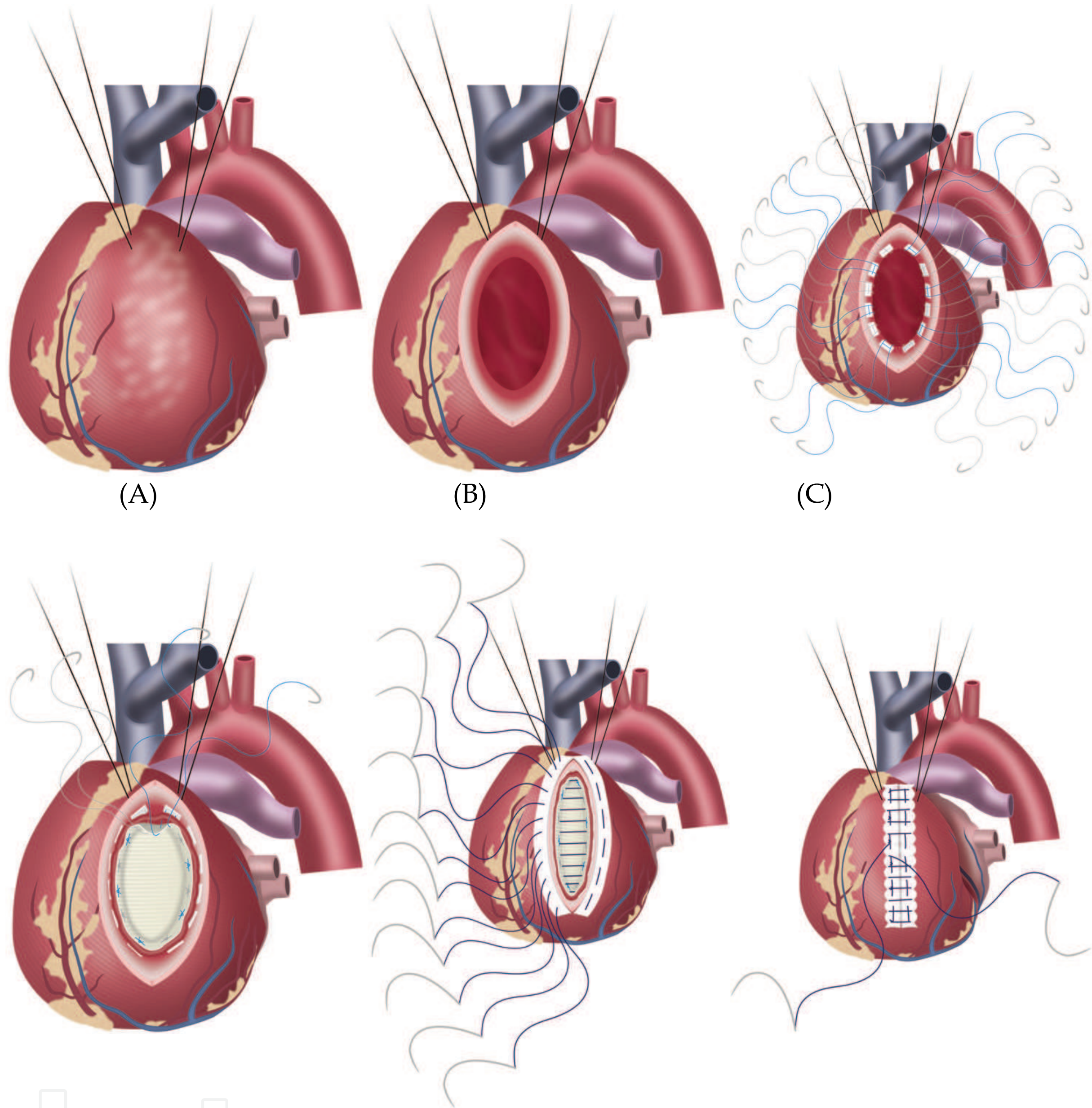


Fig. **4A**. The schema shows the heart with ICM including a posterior akinetic region. **4B.** The akinetic region is opened 1 cm proximal from the apex on the posterior wall between bilateral papillary muscles. The incision is extended toward the base of the heart, reaching 1 cm below the mitral annulus. **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[33,34)]. 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[35)]. 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[36)].

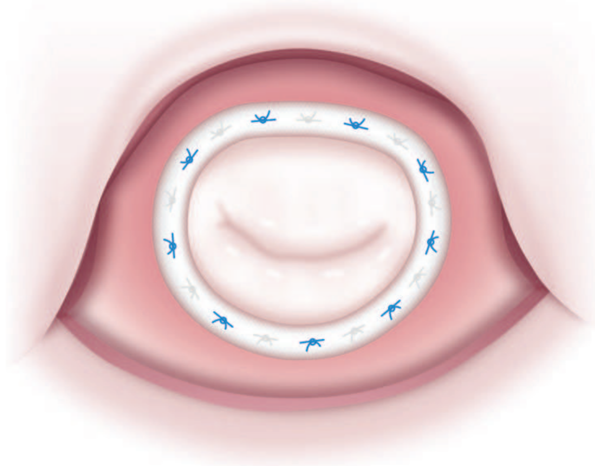
3.4 Mitral valve surgery for functional MR in patients with ICM

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[33,35-37)]. For these patients, functional MR was relieved by mitral valve plasty (MVP) including mitral annuloplasty (MAP) with an undersized flexible annuloplasty ring[38)], chordal cutting of the basal chordae[39,40)], papillary muscle approximation[41-44)], and chordal translocation[45)]. 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.

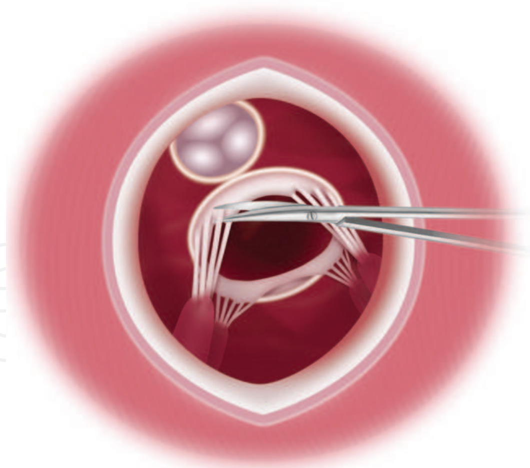
3.5 Technical details of our mitral valve surgery

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[46)]. 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 (Matsuda-ika 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.

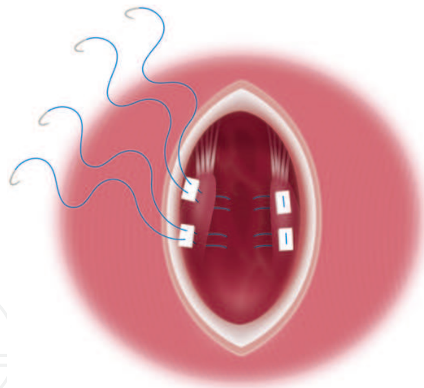


(A)



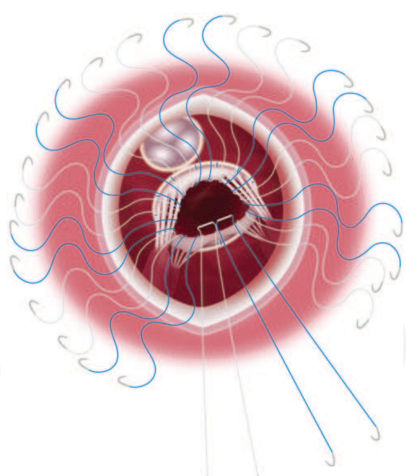
(B)

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.



(C)

(D)



(E)

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)[47)]. 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±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, cardioplumonary 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^2, SAVE 185±53 ml/m^2, PRP 154±48 ml/m^2; LVESVI: EVCPP 129±44 ml/m^2, SAVE 149±49 ml/m^2, PRP 117±50 ml/m^2). 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%; LVEDV: 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
Hospital Mortality	11 (13%)	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
Morbidity							
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/m²)	172±51	130±44*	166±46	122±47*	185±53	145±42*	154±48	114±56*
Volume reduction rate (%)				27%		22%		26%
LVESVI (mm/m²)	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.

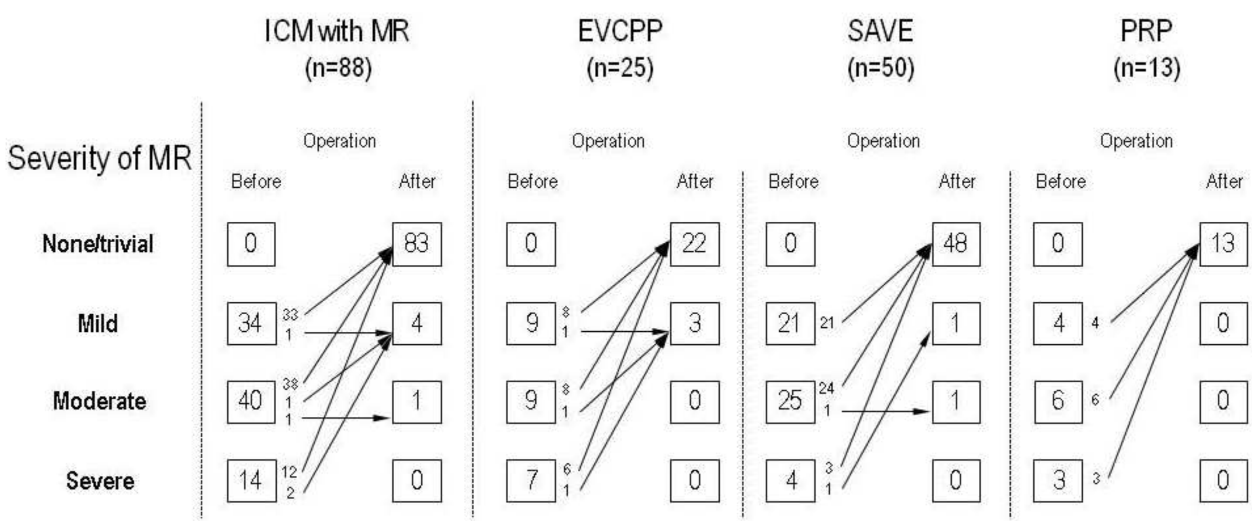


Fig. 6. The surgical effects on mitral regurgitation (MR) in patients with ischemic cardiomyopathy (ICM). In a total of 88 patients, the severity of MR was decreased after the operation. The similar effect was detected in three different procedures including endoventricular circular patch plasty (EVCCP),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

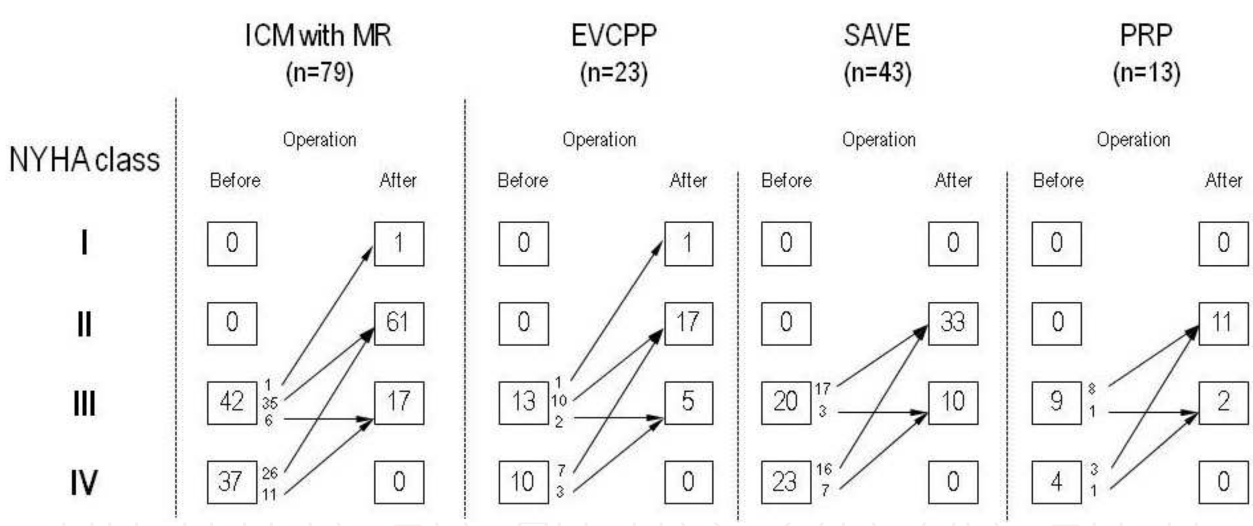


Fig. 7. The surgical effects on the New York Heart Association (NYHA) functional class in patients with ischemic cardiomyopathy (ICM) and mitral regurgitation (MR). In a total of 79 survived patients, the functional class was improved after the operation. The similar effect was detected in three different 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% (EVCPP 81%; SAVE 79%; PRP 100%) and 66% (EVCPP 50%; SAVE 66%; PRP 67%), respectively.

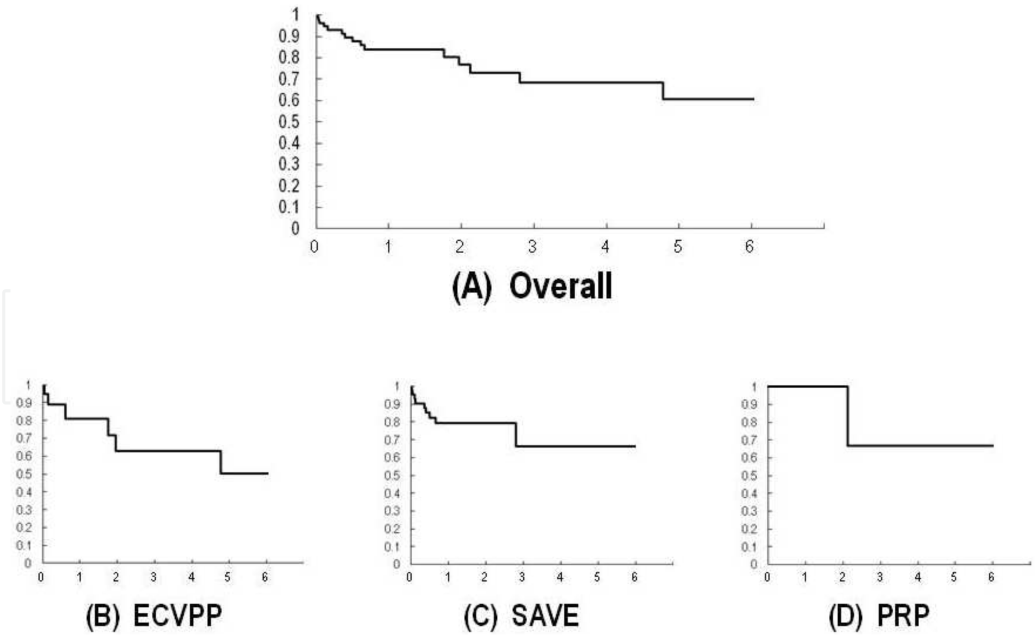


Fig. 8. Kaplan-Meier survival curves in patients with ischemic cardiomyopathy (ICM) and mitral regurgitation (MR). **(A)** In a total of 88 patients, overall survival repaired by the three different procedures including endoventricular circular patch plasty (EVCCP), septal anterior ventricular exclusion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

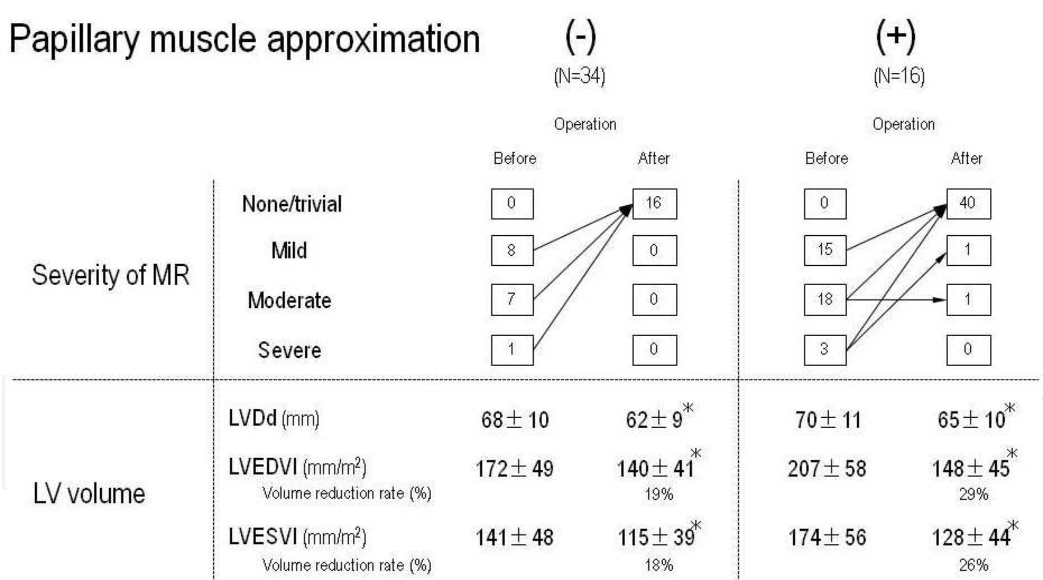


Fig. 9. The surgical effects of papillary muscle approximation on mitral regurgitation (MR) and left ventricular (LV) volume in patients repaired by the SAVE procedure and ring annuloplasty. In a total of 50 patients, the severity of MR was decreased irrespective of papillary muscle approximation. LV 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±56 vs. 141±48 ml/m^2), 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[48,49)]. However, concomitant SVR is still controversial during CABG for these patients[48,49,50)]. 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[50)]. Patient selection issues and hemodynamic effects of LV volume reduction have been proposed to explain these contradictory results[50)]. 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[51)]. According to our results, SVR is most effective when a >33% volume reduction rate achieves an LVESVI of <90 ml/m^2. No long-term benefits occur when SVR induces an LV volume reduction of <15%, leaving a residual LVESVI >90 ml/m^2. 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[48]. 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^2). 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[52,53]. 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^2, LVESV > 80 ml), coexisting MR, and need for mitral valve surgery[53,54]. 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^2) was larger than in other reports, and thus, postoperative LVESVI (104±42 ml/m^2) 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.

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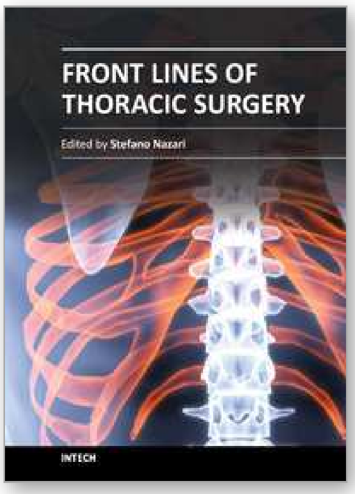

Front Lines of Thoracic Surgery

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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.