Overlapping Left Ventricular Restoration

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Cardiac transplantation, a final option of treatment for refractory heart failure, has not been a standard procedure in Japan especially, mainly because of the shortage of donors. However, surgical methods to restore native heart function, such as surgical ventricular restoration (SVR), are often effective for these cases. The Dor procedure has been used for ischemic cardiomyopathy cases presenting with broad akinetic segments. This is a fine method to exclude the scarred septum and to reduce the intraventricular cavity by encircling purse-string suture, but it may produce a postoperative spherical ventricular shape as a result of endoventricular patch repair. Also, partial left ventriculectomy is not recommended for non-ischemic dilated cardiomyopathy cases for now. A modification of these SVR and surgical approaches to functional mitral regurgitation has been named “overlapping ventriculoplasty” without endoventricular patch and resection of viable cardiac muscle, and “mitral complex reconstruction”, which consists of mitral annuloplasty, papillary muscle approximation, and suspension. Although the long-term prognosis of these procedures is undetermined, they could be an important option, at least as an alternative bridge to transplantation. This review will describe the concepts and some technical aspects of these procedures for the end-stage heart. *(Circ J 2009; Suppl A: A-13–A-18)*

**Key Words:** Dilated cardiomyopathy; Functional mitral regurgitation; Ischemic cardiomyopathy; Overlapping ventriculoplasty; Surgical ventricular restoration

**Overview**

Ischemic and non-ischemic dilated cardiomyopathy (IDCM, NIDCM) are diseases of myocardium per se, so cardiac transplantation or implantation of an artificial heart is the final option for a severely dilated heart that is refractory to medical and surgical treatment. Surgical methods to restore native heart function, such as surgical ventricular restoration (SVR), are often effective for those with extremely low cardiac function. Although SVR has clinical benefits, the reported surgical mortality has been fairly high. To determine whether SVR concomitant with coronary revascularization improves survival without heart failure, the Surgical Treatment for Ischemic Heart Failure (STICH) trial is now under investigation.

Functional mitral regurgitation (FMR) has been reported to influence late functional status and survival in IDCM and NIDCM patients. From an understanding of the tethering mechanism in both the annular and subvalvular apparatus, several procedures for FMR have been reported.

Since 2001, overlapping left ventriculoplasty (OLVP) for the severely remodeled LV, and mitral complex reconstruction (MCR) for both IMR and NIDCM, have been performed by me and my colleagues. In this review, I present the historical aspect of SVR and the concept of surgical modifications, early and midterm results, and speculate on further improvements.

**SVR and OLVP for IDCM**

Left ventriculoplasty, especially the Dor procedure basically for left ventricular aneurysm cases, has been used for cases of IDCM presenting with broad akinetic segments. The Dor procedure is a fine method for excluding a scarred septum and to reduce the intraventricular cavity with the encircling purse-string suture. It may, however, produce a postoperative spherical LV as a result of the endoventricular patch repair. This change in ventricular shape often leads to deterioration of the LV ejection fraction (EF) and development of late mitral regurgitation (MR). To preclude these changes, Isomura et al developed the septal anterior ventricular exclusion (SAVE) procedure, which uses an elliptical patch in a longitudinal direction, and have reported satisfactory results.

OLVP is a method of septal exclusion without using an endoventricular patch, mainly applicable to cases in which the anterior wall and septum are involved with infarction (Figures 1,2). This procedure is also aimed at creating a more elliptical LV shape using direct sutures, the distances between which are determined by an original intraventricular applicator as described previously.

Ueno et al recently reported that the overlapping procedure resulted in more significant LV volume reduction, maintaining the most elliptical LV shape and diastolic function compared with either the Dor or the SAVE procedure for mid-term results in IDCM. Moreover, Dang et al investigated the effects of ventricular size and patch stiffness in SVR using a finite element model, and theoretically documented that left ventriculoplasty without using a patch was more beneficial than using a patch.

**SVR and OLVP for NIDCM**

Since partial left ventriculectomy (PLV) as a LV volume reduction surgery was first reported by Batista in 1996, the
results of many series of PLV have been reported. Surgical results were not favorable, and thus PLV is not currently a standard procedure for treating end-stage cardiomyopathy. Isomura et al. focused on the difference in the location of lesion involved, even in cases of NIDCM, and they have used the Batista procedure for cases of NIDCM with a lateral wall lesion and the SAVE procedure for cases of NIDCM with an anteroseptal lesion. The OLVP procedure reduces LV volume by doubling in part the LV anterior wall around the apex and creates an elliptical LV shape without ventriculectomy. The other theoretical presumable merits of OLVP without ventriculectomy, without a patch, and with partial overlapping of viable wall are (1) preservation of major coronary arteries without ventriculectomy, (2) partial assist effect of the excluded overlapping wall, (3) reversibility of the ventricular reconstruction, and (4) a partial girdling effect of the overlapped wall (Figures 1, 2).

**Concept of SVR**

**LV Volume Reduction Surgery**

Laplace’s law can account for the concept of LV volume reduction surgery: the reduction of LV volume by doubling the LV anterior wall around the apex and creating an elliptical LV shape without ventriculectomy. This concept is illustrated in Figures 1 and 2.
reduction surgery. Briefly, the wall stress increases in proportion to the LV dimension and inversely in proportion to the wall thickness. Thus, LV partial resection to reduce the LV dimensions carries a decrease in wall stress, which results in a reduction of myocardial oxygen consumption. Horii et al. considered that patients with an enlarged heart and a preoperative LV end-systolic volume index (LVESVI) greater than 150 ml/m² body surface area (BSA) had a poor prognosis relative to those presenting with a LVESVI less than 150 ml/m² BSA when treated with isolated mitral annuloplasty (MAP), which showed the limitation of isolated MAP in an extremely enlarged heart.13

Controversy exists regarding the effects of LV volume reduction surgery in IDC. Yamaguchi et al. reported that patients with an enlarged heart and a preoperative LVESVI greater than 100 ml/m² BSA had a poor prognosis and a high incidence of heart failure when undergoing isolated CABG16 and also showed that left ventriculoplasty performed as an adjunct to CABG improved their prognoses.27 Based on those results, LV volume reduction surgery should have some significant role.

Helical Structure of Myocardial Loop Fiber Orientation

By Newton’s simple law of motion, if the volume of a spherical and spherical mass are the same, the force of the basal segment for reducing the volume of the spherical shape needs 1.37-fold more acceleration than an ellipsoidal shape.18 Buckberg et al. emphasized the advantage of an elliptical shape in terms of myocardial fiber orientation.19 The LV has a helical architecture consisting of transverse basal loop and oblique apical loop fibers, whose contraction and extension produce twisting of the helical structure. Blood outflow occurs on contraction of the loop fiber and inflow occurs on extension, which carries the cardiac systolic and diastolic wall motion. The elliptical ventricular shape maximizes the efficacy of outflow and inflow within the cardiac cycle, but efficacy is reduced with progression in LV sphericity during the remodeling process. Thus, making the ventricular shape as elliptical as possible, as well as reducing chamber size in left ventriculoplasty, is essential for restoring LV function. Moreover, simple resection of the akinetic segments or reducing the chamber size by exclusion of noncontracting ventricle cannot keep the continuity of the loop fibers, which may inhibit the systolic pump function produced by the helical structure.

Recently, Tumkosit et al. reported that LV apical relaxation velocities in participants with LV spherical remodeling were reduced compared with those of healthy individuals, indicating the effect of LV shape on diastolic function.20

FMR in the Enlarged Heart

Cause and Prevention of FMR

The presence of FMR is considered to indicate the need for aggressive treatment of patients with serious dilated heart failure.21 LV enlargement results in lateral displacement of the anterior and posterior papillary muscles, leading to an extension of the distance between them. The papillary muscles are pulled towards the posterior wall and the apex, which causes tethering of the valve leaflets and their apical displacement. These mechanisms are mainly responsible for the development of FMR which cannot be radically corrected without repairing the subvalvular structure. It is highly questionable whether the efficacy of isolated MAP for dilation of the mitral annulus persists during long-term follow up.

Indication for Surgical Treatment of IMR

In the recent review by Gorman and Gorman, there are so many controversies with very little evidence to support that surgical intervention for IMR improves longevity, reduces heart size or limits symptoms. They suggest that LV pump function is more influenced by the infarcted segments compared with MR, and that a high incidence of recurrent MR is likely to produce inconsistent surgical results.23 The prognosis of IMR does not correlate with the degree of MR at rest, but with the degree of exercise.21 Thus, the fact that the degree of preoperative MR does not reflect its degree in daily life outside the hospital would also be a major factor in the inconsistent surgical results.

Procedures for FMR

Undersized (Reduction) MAP Bulling et al. reported the effectiveness of undersized MAP (UMAP) to enhance the mitral valve coaptation zone.24 Excessive shortening of the distance between the anterior and posterior annulus, however, leads to an extension of the distance between the mitral annulus and LV posterior wall, which has the potential to worsen the tethering. Persistence or recurrence of FMR in the chronic phase after UMAP has been reported,25,26 so a variety of surgical procedures are advocated as an adjunct to UMAP. Also, relative mitral stenosis after reduction annuloplasty has been reported.27

Enhancement of Coaptation Zone

To further enhance the coaptation zone, surgical interventions, including chordal cutting,28 pericardial patch enlargement of the mitral leaflet, and the use of a remodeling ring specifically designed to treat asymmetric leaflet tethering,9,30 have been reported as adjuncts to MAP, with promising long-term results for some methods. Cutting the anterior leaflet second-order “strut” chordae in the chordal cutting procedure is, however, reported to alter LV geometry and impair LV systolic function.31

Surgical Approach to the Papillary Muscles

A variety of surgical procedures, including the “papillary muscles sling” procedure,32 and surgical relocation of the posterior papillary muscle,33 have been performed to correct papillary muscle displacement.34 Papillary muscle approximation (PMA) combined with or without OLVP depending on the individual case has been performed by me and my colleagues since 2003.3,35 PMA is a surgical method of joining the entire papillary muscles side-by-side from their bases to their heads (Figure 2). PMA is considered to correct the lateral displacement of the papillary muscles and reduce the lateral tethering of the mitral valve leaflets, thus attenuating FMR. From the viewpoint of ventricular shape, PMA shifts the LV posterior wall to the center of the LV short axis by reducing the radial diameter and also reduces the posterior tethering of mitral valve leaflets. Moreover, a more elliptical LV shape can be obtained when PMA is concomitantly performed with OLVP, which reduces LV volume around the apical portion, resulting in volume reduction in the posterior LV cavity especially around the basal portion.

Mitral Complex Reconstruction (MCR) PMA has proven effective for reducing the tethering of the mitral leaflets in the mid-term results, as previously described,35 but progression of LV dilation may recur in the long-term follow-up, leading to worsening of tethering as a result of re-extension of the posterior wall. Recently, I reported an
adjunctive technique of placing a subvalvular CV4 EPTFE suture between the site of chordal attachment of the papillary muscles and the annulus at the center of the posterior mitral leaflet. This procedure, which has been termed papillary muscles suspension (PMS), is considered to prevent future deterioration of tethering by fixing an adequate distance between the mitral annulus and the site of chordal attachment of the papillary muscles.\(^{36}\)

**Strategy and Technical Aspects of Modified Surgical Treatments for Severely Dilated Heart Failure**

**OLVP**

OLVP is performed to reshape the remodeled LV (Figure 2).\(^ {8,9} \) The concept of this procedure is LV volume reduction without using a patch or ventriculectomy. A longitudinal LV incision of approximately 10 cm is made on the anterior wall along the left anterior descending artery. The diagonal branches are usually kept intact. The free edge of the lateral side is sutured to the septal wall using an original cone-shaped 72- or 95-ml sizer to determine the suture line for making the LV shape elliptical, but not to reduce the LV volume too much, by controlling the suture line along the sizer. When the anteroseptal wall is not viable, a second layer, which is not widely overlapped, is sutured just above the first suture line to prevent wall motion restriction by the second scarred layer. This resembles the procedure reported by Guilmet et al\(^ {37} \) and Stoney et al\(^ {38} \) but their indication was LV aneurysm and the lateral wall was largely covered by a scarred septal wall, which may deteriorate diastolic function. When the anteroseptal wall is viable, and the medial side’s edge is overlapped to the free wall, OLVP creates a more elliptical LV shape.
Overlapping LV Restoration

MCR

My preferred surgical strategy for FMR is to reconstruct the annulus and subvalvular apparatus of the mitral valve (ie, MCR) (Figure 2).35,36 MCR consists of MAP using a semi-rigid total ring, PMA and PMS. PMA joins the entire papillary muscles from their base to their heads with 3 pledgeted mattress sutures of 3-0 prolene. Shortening the distance between the papillary muscles reduces the lateral and backward tethering of the mitral valve. PMS fixes the distance between the papillary muscles’ heads and the mitral annulus. This adjunctive method places a subvalvular CV4 EPTFE suture between the chordal attachment site of the papillary muscles and the annulus at the center of the posterior, or more recently, the anterior mitral leaflet, considering a more physiological geometry.39 This suture is passed through the annuloplasty ring. I believe that PMS maintains the geometry of the mitral complex and prevents future deterioration of tethering. PMA and PMS are usually indicated when the papillary muscle distance at end-diastole is greater than 30 mm in the short-axis view on transthoracic echocardiography, and are performed by left ventriculotomy when ventriculoplasty is necessary or through the mitral annulus when the LV is not incised. MAP with a Physio-ring was done in all cases. Recently, I have preferred to use a just-sized mitral annuloplasty ring to an undersized one because MCR restores sufficient coaptation. OLVP only, OLVP + MCR or MCR only is selected according to each individual case (Figures 3, 4).

Early and Mid-Term Results

OLVP and MCR were performed to reduce LV volume, change the LV shape, and control MR without resecting cardiac muscle in 104 cases of end-stage DCM (IDCM 57, NIDCM 47, excluding LV aneurysm cases; 89 men, 15 women, mean age 61±13 years). Preoperative EF was 22±9%, LVEDV was 170±54 ml/m², LVdD was 70±9 mm, and B-type natriuretic peptide was 1.20±1.14 ng/ml. Performed procedures were OLVP only in 22, OLVP + MCR in 48, and MCR only in 34 cases. Recently, mitral tethering has been treated by modified PMA with PMS to a posterior or anterior prosthetic mitral annulus in 39 cases. Only 3 emergency NIDCM patients died of non-cardiac cause (cerebral bleeding and sepsis) within 30 days (3%). Comparative pre- and postoperative hemodynamics were as follows: EF 22.49±31±10%, LVEDV 173±47→113±32 ml/m², LVdD 71±9→63±7 mm. MR grade improved from 3.3±1.1 to 0.2±0.5. New York Heart Association class improved from 3.5±0.8 to 1.3±0.5, and the 1- and the 3-year actuarial survival rates were 91% and 87% in IDCM cases and 77% and 61% in NIDCM cases, respectively.

Conclusion

Although SVR needs more investigation in terms of its indication, comparison of the variety of surgical procedures, and long-term prognosis, it often improves clinical symptoms postoperatively, even in the case of severely deteriorated LV function. SVR, including OLVP, is considered an option of surgical treatment that is effective for severe heart failure with promising long-term results.

References


