Review

Left Ventricular Reconstruction for Severely Dilated Heart

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Overview

Surgical interventions for ischemic or non-ischemic heart failure refractory to medical treatment include the implantation of an artificial heart, tissue engineering medicine, and myocardial substitute, in addition to conventional coronary revascularization for ischemic heart disease (IHD) and undersized mitral annuloplasty (UMAP) for functional mitral regurgitation (FMR) causing myocardial damage. Remarkable progresses have been made in these surgical methods, but they have not necessarily reached a satisfactory level for clinical application. Cardiac transplantation, a final option of treatment for refractory heart failure, has not been a standard procedure especially in Japan, mainly due to the shortage of donors, despite a number of efforts to make it a standard procedure made so far by medical personnel and other parties concerned.

Ischemic cardiomyopathy (ICM) or non-ICM is a disease of myocardium per se; thus cardiac transplantation or implantation of an artificial heart would be a final option of surgical methods for severely dilated heart failure refractory to treatment. However, surgical methods to restore native heart functions are often effective for those with an extremely low cardiac function. Although a long-term prognosis of these procedures is undetermined, they are considered to be an important option of treatment, at least as an alternative or biologic bridge to transplantation or artificial heart implantation.

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A. Procedures of Left Ventriculoplasty

1. Left ventriculoplasty for left ventricular (LV) aneurysm

Left ventriculoplasty has been developed as a method of LV aneurysmectomy. Linear aneurysmectomy, reported by Cooley et al. in 1959,[1)] is still applicable to special situations where the majority of dyskinetic segments are limited to the LV free wall. For more common cases of left anterior wall infarction associated with significant injury to the ventricular septum, a variety of surgical methods to perform endoventricular patch repair were reported as procedures for the scarred septum by Jatene,[2)] Dor et al.,[3)] and Cooley[4)] almost at the same time. Among these procedures, the Dor procedure has been widely used due to its simplicity of the septal exclusion technique.[5)]

2. Left ventriculoplasty for ICM

Left ventriculoplasty described above, especially the Dor procedure, has been recently applied to cases of ICM presenting with broad akinetic segments.[6)] The Dor procedure is a fine method to exclude the scarred septum and to reduce the intraventricular cavity by encircling purse-string suture. This procedure may produce relatively broad akinetic segments and a postoperative spherical LV shape as a result of the application of endoventricular patch repair. These changes in ventricular shape often lead to a deterioration of LV ejection fraction and a development of late MR.[7)] To preclude these changes, Isomura and Suma et al. developed the septal anterior ventricular exclusion (SAVE) procedure by using an elliptical patch in a longitudinal direction and have reported satisfactory results.[8)] Overlapping procedure, which we have previously developed, is a method for septal exclusion without using an endoventricular patch, mainly applicable to cases where the anterior wall and septum are involved

with infarction. This procedure is also aimed at converting the LV shape more elliptically by direct suture, whose distances are designed by our original intraventricular applicator.[9] Ueno et al. recently reported that the overlapping procedure provided more significant LV volume reduction, maintaining the most elliptical LV shape and diastolic function, compared to the Dor procedure and the SAVE procedure in midterm results.[10] Moreover, Dang et al. investigated the effects of ventricular size and patch stiffness in surgical ventricular restoration using a finite element model and theoretically documented that left ventriculoplasty without using patch was more beneficial than other procedures.[11] Although further investigations are required as to which procedure is more effective on individual cases, the overlapping procedure seems to be a promising option of treatment for ICM.

3. Left ventriculoplasty for non-ICM

Since partial left ventriculectomy (PLV) was first reported by Batista et al. as LV volume reduction surgery in 1996,[12] the results of many series of PLV have been reported by a number of investigators.[13] Surgical results of these series were not favorable, and PLV is not a current standard procedure to treat end-stage cardiomyopathy. Isomura et al. focused on the difference in the location of lesion involved even in the case of non-ischemic dilated cardiomyopathy (NIDCM). They have employed the Batista procedure for the case of NIDCM with lateral wall lesion and applied the SAVE procedure, which was developed in conformity with septal exclusion for LV aneurysm reported by Cooley et al., to the case of NIDCM with anteroseptal lesion.[14] We also developed a new method of overlapping ventriculoplasty (OLVP) and applied it to the case of NIDCM.[9] This procedure doubles in part the LV anterior wall around the apex and converts the LV shape elliptically without ventriculectomy.[9] We also performed the procedure of papillary muscles approximation (PMA) to preclude late MR as an adjunct to OLVP, depending on the situation of the individual case.[15] Although these procedures have been developed as those for NIDCM originally, we have also applied them to the cases of ICM (Figs. 1 and 2), as described above.

B. The Concept of Left Ventriculoplasty

Left ventriculoplasty is a surgical method to reduce the wall stress and to improve the systolic cardiac function by reducing the LV cavity and remodeling the enlarged, spherical ventricle to an elliptical shape. Therefore a variety of surgical procedures reported are required not only to reduce the LV chamber size, but also to optimize the ventricular shape. The value of left ventriculoplasty would be more significant in ICM cases through the exclusion of akinetic as well as dyskinetic segments leading to restoration of the LV function.

It is well known that the presence of concomitant FMR is a strong determinant of prognosis; thus its control is also essential to achieving favorable long-term results. Recently, a tethering of the mitral valve leaflets due to an enlargement of the LV cavity was reported to be mainly responsible for the development of FMR. Tethering of the valve leaflets cannot be corrected by UMAP alone, resulting in a late recurrence of regurgitation as previously reported. To prevent the recurrence of FMR, it seems to be necessary to repair the total mitral complex, including valves, mitral annulus, chordae, and papillary muscles.

1. LV volume reduction surgery

LaPlace's law can account for the concept of LV volume reduction surgery. Briefly, the wall stress increases in proportion to the LV dimension and in inversely proportion to the wall thickness. Thus, LV partial resection to reduce LV dimensions carries the decrease in wall stress, which results in the reduction of myocardial oxygen consumption. In Europe and the United States, negative opinions are dominant in terms of the value of LV volume reduction surgery for NIDCM, due to unfavorable surgical results of partial left ventriculectomy reported by McCarthy and associates.[13] Horii et al. described that patients with an enlarged heart of preoperative LV end-systolic volume index (LVESVI) greater than 150 mL/m^2 body surface area (BSA) had a poor prognosis relative to those presenting with a heart of LVESVI below 150 mL/m^2 BSA when treated with isolated mitral annuloplasty (MAP), which showed the limitation of isolated MAP in an extremely enlarged heart.[16] It would be necessary to reevaluate the clinical significance and methods of LV volume reduction surgery, especially in Japan where cardiac transplantation has been rarely performed.

Controversy exists regarding the effects of LV volume reduction surgery on ICM. It was reported that long-term prognosis of patients with IHD associated with poor LV function was equivalent to that of those receiving medical treatment only, when assessed by the presence and degree of heart failure.[17] Luciani et al. reported that, however, LV ejection fraction was improved, whereas the LV dimension and degree of heart failure became worsened in long-term follow up after coronary artery bypass graft-

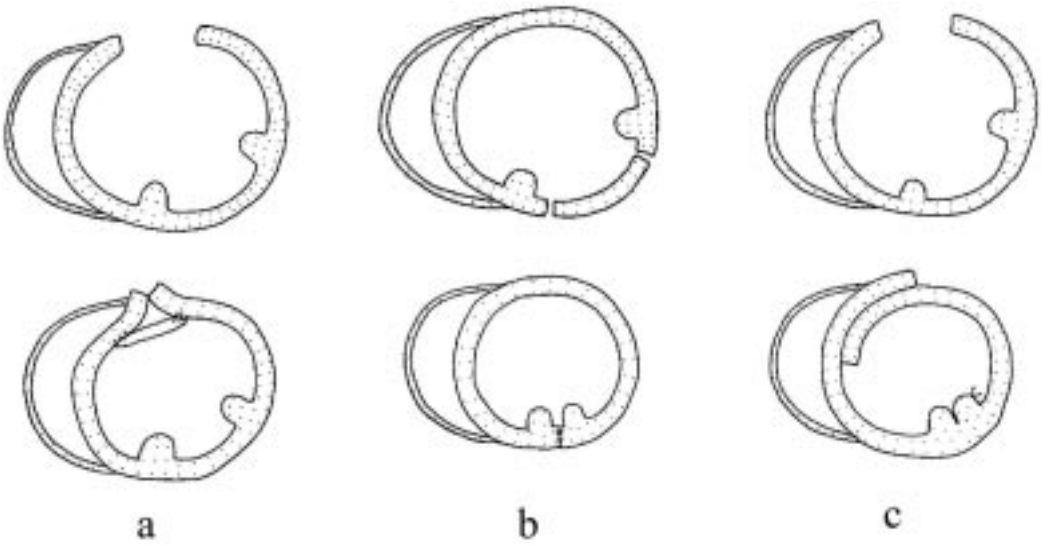

Fig. 1. Schemata of the Dor procedure, Batista procedure, and Overlapping-type left ventriculoplasty (OLVP).

a: Dor procedure: LV volume reduction is accomplished by an endoventricular patch in the anterior and septal portions. The basic concept is the same as Cooley's method and the septal anterior ventricular exclusion (SAVE) procedure.

b: Batista procedure: LV lateral wall is broadly resected and closed with direct suture.

c: OLVP: This procedure performs ventriculotomy of the anterior wall without ventriculectomy, and doubles in part the LV anterior wall by overlapping the incised wall around the apex. Papillary muscles approximation (PMA) is also performed as an adjunct to OLVP, depending on the situation of the case. The figure shows the procedure for NIDCM.

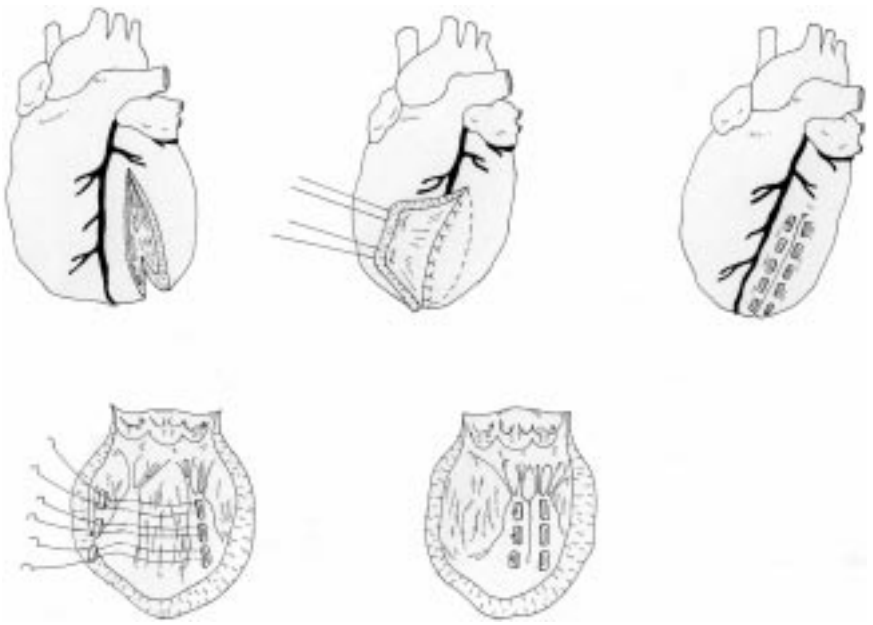

Fig. 2. Overlapping-type left ventriculoplasty (OLVP) and papillary muscles approximation (PMA).

Upper: The overlapping-type procedure includes an incision in the enlarged LV free wall. The left incision margin is sutured to the septal wall, and a part of excluded myocardium is sutured to the LV free wall. This overlapping-type procedure doubles in part the LV anterior wall around the apex and converts the LV shape elliptically without ventriculectomy.

Lower: PMA reduces posterior LV cavity volume and carries anterior shifting of the LV posterior wall, which would be beneficial for attenuating posterior displacement of the papillary muscles. PMA is also considered effective for correcting lateral displacement of papillary muscles by joining them side-by-side. These changes in the displaced papillary muscles would prevent a recurrence of FMR due to tethering when future progression of LV dilation recurs in the long-term follow up.

ing (CABG).[18] Yamaguchi et al. reported that patients with an enlarged heart of preoperative LVESVI greater than 100 mL/m^2 BSA had a poor prognosis and a high incidence of heart failure when receiving isolated CABG,[19] and also showed that left ventriculoplasty performed as an adjunct to CABG improved their prognoses.[20] Based on these results, LV volume reduction surgery may have some significant role at least in the treatment of ICM.

2. Helical structure of myocardial loop fiber orientation

Buckberg and Torrent-Guasp et al. emphasized the advantage of elliptical shape in terms of myocardial fiber orientation.[21] The LV consists of helical architecture of the transverse basal loop and oblique apical loop fiber, 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 cardiac systolic and diastolic wall motion. Elliptical ventricular shape maximizes the efficacy of outflow and inflow within the cardiac cycle, but the efficacy is reduced by progression in LV sphericity due to a remodeling process. Thus converting ventricular shape as elliptically as possible would be essential to a restoration of the LV function, as well as reducing chamber size in left ventriculoplasty. Moreover, a simple resection of the akinetic segments or reduction of the chamber size by an exclusion of noncontracting ventricle cannot keep continuity of the loop fiber, which may inhibit systolic pump function produced by its helical structure.

3. FMR in an enlarged heart

(a) The cause and prevention of FMR. MR occurring in ICM or NIDCM cases as a result of LV remodeling is an important determinant of poor prognosis. In patients with ischemic MR (IMR), the prognosis does not correlate with the degree of MR at rest, but with the degree on exercise. Thus, the presence of MR is considered to be indicative of aggressive treatment in patients with seriously dilative heart failure.[22] This type of MR is described as FMR, which is defined as regurgitation resulting from distortion in the subvalvular structure associated with an enlarged LV despite the presence of a normal structure of valvular leaflets and chordae tendineae. Since the number of patients presenting with a medically uncontrollable IMR is increasing among those receiving coronary revascularization by percutaneous coronary intervention (PCI), the clinical importance of surgical treatment for these patients is being enhanced.

The LV enlargement results in lateral displacements of the anterior and posterior papillary muscles, leading to an extension of the distance between the anterior and posterior papillary muscles. The papillary muscles are pulled in a direction towards posterior wall and the apex, which causes a tethering of valve leaflets and their apical displacement. These mechanisms are mainly responsible for the development of FMR;[23] thus FMR cannot be radically corrected without the repair of subvalvular structure. It is highly questionable whether the efficacy of isolated MAP for a dilation of the mitral annulus persists during the long-term follow up.

Bolling et al. reported the effectiveness of UMAP to enhance the mitral valve coaptation zone.[24] Excessive shortening of the distance between the anterior and posterior annulus, however, leads to extending the distance between the mitral annulus and the LV posterior wall, which may have the potential for a worsening of the tethering. Persistence or recurrence of FMR in the chronic phase after UMAP has been reported;[25,26] thus a variety of surgical procedures are advocated as an adjunct to UMAP.

(b) Indication for surgical treatment of IMR. The effectiveness of mitral valve surgery on ICM remains to be elucidated. In Guidelines for the Clinical Application of Bypass Grafts and the Surgical Techniques, published by the Japanese Circulation Society in 2006, the clinical value of mitral valve surgery for IMR is described as follows[27]: (1) Patients undergoing CABG who have severe MR should have concomitant mitral correction at the time of CABG (Class IIa, Evidence Level B). (2) Patients undergoing CABG who have moderate MR are recommended to have concomitant mitral valve surgery at the time of CABG (Class IIb, Evidence Level C). Controversy exists especially in terms of the indication for surgical treatment of moderate MR. In regard to patients with moderate MR undergoing isolated CABG, some reports described that MR was temporally improved in the early postoperative period, but recurred later in majority of patients,[28,29] whereas other reports described that isolated CABG was effective for MR.[30] As is pointed out in the recent review by Gorman et al., there are so many controversies arising with very few evidences to support that surgical interventions for IMR improve longevity, reduce heart size, or limit symptoms.[31] They suggest that LV pump function would be more influenced by the infarct segments compared to MR, and that a high incidence of recurrent MR is quite likely to produce inconsistent sur-

gical results.[31] The prognosis of IMR does not correlate with the degree of MR at rest, but with the degree on exercise, as previously described. Thus, we consider that the degree of preoperative MR not reflecting its degree in daily life outside the hospital, would also be a major factor leading to inconsistent surgical results.

(c) Mitral valve repair and valve replacement. Threre are many reports describe that the early and late results of MAP are both superior to those of mitral valve replacement (MVR),[32] whereas some reports describe that the results are equivalent.[33] Chordal cutting with MVR may cause further deterioration of systolic pump function, especially in patients with poor LV function. Even in a patient undergoing MVR with the preservation of all chordae tendineae, the mechanical contribution of the preserved chordae to LV function seems not to be equivalent to that of marginal chordae. Mitral valve-ventricule continuity seems to be important for LV systolic pump function; thus MAP should be selected if possible, rather than MVR.

(d) Adjuncts to MAP. UMAP, reported by Bolling et al., is aimed at enhancing the mitral valve coaptation zone, but is associated with a high incidence of the recurrence of FMR, as previously described. It seems to be difficult to radically correct the tethering only by UMAP; thus a variety of surgical procedures are reported as an adjunct to UMAP.

(1) Enhancement of the coaptation zone: For further enhancement of the coaptation zone, surgical interventions including chordal cutting,[34,35] pericardial patch enlargement of the anterior mitral leaflet,[36] and the use of a remodeling ring specifically designed to treat asymmetric leaflet tethering[37] have been reported as adjuncts to MAP, with promising long-term results in 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.[38]

(2) Surgical approach to alter the shape of mitral annulus: The severity of IMR was reported to correlate mainly with papillary muscle leaflet tethering length, but not with mitral annular dilation.[39] As is previously described, isolated UMAP cannot radically correct IMR. In a more detailed investigation, it was reported that a conversion of the normal saddle shape into a more flatter shape of the mitral annulus may occur as well as annular dilation in a heart involved with infarction, which would be related to a deterioration of tethering of the valve leaflets.[40] These data suggest that a saddle-shaped ring have the potential to repair IMR more effectively than a conventional flat ring.[40]

(3) Edge-to-edge repair: Alfieri et al. reported a relatively good mid-term result of the edge-to-edge repair technique in its clinical application to FMR.[41] This procedure creates a double-orifice mitral valve to reduce MR, by approximating the free edges of the leaflets at the site of regurgitation, usually with a running suture. The Alfieri edge-to-edge mitral repair is, however, reported to be ineffective for acute IMR without concomitant annuloplasty in an experimental setting.[42]

(4) Surgical approach to the papillary muscle: Since the lateral, posterior, or apical displacement of papillary muscles is mainly responsible for the development of FMR, a variety of surgical procedures, including the "papillary muscles sling" procedure[43] and surgical relocation of the posterior papillary muscle,[44] have been performed to correct the papillary muscle displacement.[45–47] We have performed PMA combined with or without OLVP, depending on the individual case.[48] PMA is a surgical method to join the entire papillary muscle side-by-side from the bases to the heads of both of them (Fig. 2). PMA is considered to correct the lateral displacement of papillary muscle and reduce the lateral tethering of mitral valve leaflets, thus attenuates FMR. From a viewpoint of ventricular shape, PMA shifts the LV posterior wall in a direction to the center of the LV short axis by reducing radial diameter and reduce the posterior tethering of mitral valve leaflets. Moreover, a more elliptical LV shape can be obtained when PMA is concomitantly conducted with OLVP that reduces LV volume around the apical portion, as a result of volume reduction in the posterior LV cavity, specially around the basal portion.

(5) An attempt to apply mitral complex reconstruction to FMR: PMA proved to be effective for reducing the tethering of mitral leaflets in the mid-term results, as previously described, but the future progression of LV dilation may recur in the long-term follow up, leading to a worsening of the tethering as a result of re-extension of the posterior wall. Recently, we performed an adjunctive method to place a subvalvular CV4 EPTFE suture between the site of the chordal attachment of papillary muscles and the annulus at the center of the posterior mitral leaflet. This suture is passed up through the annuloplasty ring, and suspends the papillary muscles, followed by a saline infusion test so that leaflet coaptation occurs accurately in the level as the plane crossing the mitral annulus (Fig. 3). This procedure, which we termed papillary muscles suspension (PMS), is considered to prevent a future deterioration of tethering, by fix-

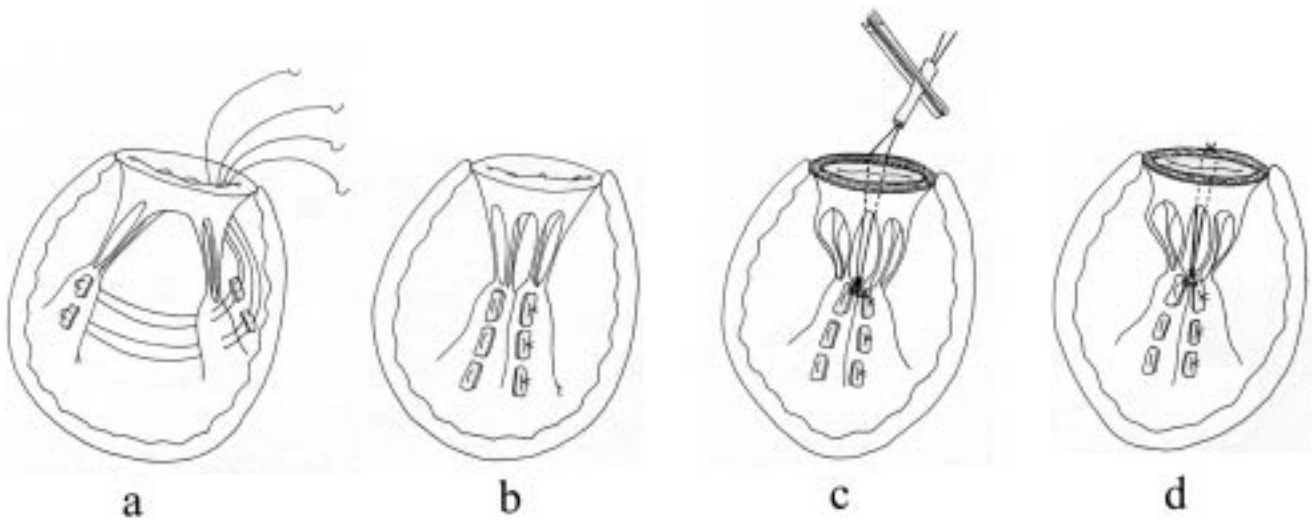

Fig. 3. Mitral complex reconstruction.

a: PMA is carried out using autologous pericardium pledgetted mattress sutures through the mitral annulus or the left ventriculotomy.

b: PMA is completed by placing those sutures through the trabeculae around the bases of the anterior and posterior muscles, the deepest being just below the site of chordal attachment.

c: A subvalvular CV4 EPTFE suture is placed between the site of the chordal attachment of the papillary muscle and the annulus at the center of the posterior mitral leaflet. This suture is passed up through the annuloplasty ring and the tourniquet.

d: The length of CV4 suture is adjusted by a left ventricular saline infusion test after the mitral ring annuloplasty was completed. The CV4 suture is then tied where leaflet coaptation occurs in the plane of the annulus.

ing an adequate distance between the mitral annulus and the site of the chordal attachment of papillary muscles.[49)]

C. Current Assessment of Left Ventriculoplasty

1. ACC/AHA Guideline Update for the Diagnosis and Management of Chronic Heart Failure in the Adult[50)]

The effectiveness of mitral valve repair or replacement is not established for severe secondary MR in refractory end-stage heart failure (Class IIb, Level of Evidence C). And partial left ventriculectomy is not recommended in patients with non-ICM and refractory end-stage heart failure (Class III, Level of Evidence C).

2. Guidelines for the Clinical Application of Bypass Grafts and the Surgical Techniques, published by the Joint Task Force of the Japanese Circulation Society in 2004 and 2005[51)]

Class I: CABG for severe multivessel coronary disease presenting with a proven profound myocardial ischemia associated with poor LV function (Level of Evidence B).

Class IIa: Left ventriculoplasty as an adjunct to CABG for the case of poor LV function as a result of LV remodeling following myocardial infarction (Level of Evidence B).

Class IIb: CABG and left ventriculoplasty for the case of severely deteriorated LV function after broad myocardial infarction due to multivessel coronary disease (Level of Evidence C).

3. STICH trial (Surgical Treatment for Ischemic Heart failure)[52)]

A prospective multicenter study for patients with heart failure due to IHD is under progress mainly in Europe and the United States. Following issues are investigated with an expectation of promising results:

1) whether CABG combined with medical treatment improves long-term results compared to isolated medical treatment without CABG;

2) whether left ventriculoplasty as an adjunct to CABG combined with medical treatment improves long-term prognosis compared to CABG combined with medical treatment.

D. Conclusion

Although left ventriculoplasty needs more investigation in terms of its indication, comparison of a variety of surgical procedures, and long-term prognosis, it frequently improves clinical symptoms postoperatively, even in the case of a severely deteriorated LV function. Left ventriculoplasty reduces the LV volume and often improves LV function in patients with ICM or NIDCM, presenting with spherical LV enlargement associated with FMR. Left ventriculoplasty is considered an option of surgical treatment that is effective for severe heart failure with promising long-term results.

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