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Surgical Treatment for Functional Mitral Regurgitation

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Surgery for functional mitral regurgitation (FMR) was reviewed. As the mechanism of FMR is still being elucidated, surgery for FMR, especially ischemic mitral regurgitation evolved from coronary bypass surgery (CABG) with/without mitral valve replacement, to repair mitral leaflet/chordate/papillary muscles and the left ventricle is required. Currently, the best efforts are made regarding the treatment of mitral leaflet tethering or tenting including that of the posterior leaflet and the treatment of ventricular disease. Although the understanding of FMR is increased and the surgical repair technique becomes more sophisticated, prognosis of the patient is not necessarily satisfactory when the amount of residual myocardium is limited. Further investigation is necessary to solve the problem of ventricular disease. (*Circ J* 2009; **Suppl A:** A-23 – A-28)

Key Words: Coronary artery disease; Dilated cardiomyopathy; Mitral valve; Myocardial infarction; Surgery

Functional mitral regurgitation (FMR) is characterized not only by the presence of mitral regurgitation (MR) but also by the absence of organic/morphological disease in the mitral valve itself (eg, leaflets and chordate tendinease). In other words, FMR is a ventricular disease with a phenotype of valvular disease. According to its etiology, FMR can be categorized into 2 groups: ischemic and non-ischemic. In this review article, ischemic MR (IMR) will mainly be discussed.

IMR, Historical Change of Its Concept – From "Papillary Muscle (PM) Dysfunction" to "Ventricular Disease"

It has been well known that IMR develops after myocardial infarction; IMR had been believed to be caused by PM dysfunction as reported by Burch et al in 1963[1] However, several experimental[2] and clinical[3] series showed that PM disease alone does not induce MR, which suggests that the etiology of IMR is a dysfunction of the LV area around the PM base or of the whole LV, especially its sphericalization due to remodeling. One of the reasons for the slow progress in the research of this field is a lack of suitable large animal models of IMR in the past as compared to the modern era[4] and the limitation of the quality of echocardiography in the clinical setting. Recent advancement of echocardiography, especially the 3-D one[5] and MRI[6] helps progress in this field.

Currently, it is widely accepted that IMR is a ventricular disease. Initially, mitral/LV geometry in IMR was reported by using echocardiography in the 1970 s[3] and in the 1990 s by Miller's group from Stanford using a radiopaque 3-D marker method[7,8] and the Edmunds team from Pennsylvania using 3-D ultrasonic crystals[9,10] These foregoing studies were further reinforced and detailed by Levine et al[11] from MGH by using 3-D echocardiography[12]

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Current Understanding of Geometry in IMR

In a mitral valve with IMR, the following geometric abnormalities at systole can be seen (**Figure 1**):

· **IMR Factor 1** Leaflet "tenting" or "tethering" with its incomplete closure. The phenomenon is described as type III MR or incomplete mitral leaflet closure, too.

· **IMR Factor 2** Dilatation of mitral annulus.

· **IMR Factor 3** Lateral dislocation of the PMs and their tips.

· **IMR Factor 4** Abnormal geometry of the LV wall, especially LV sphericalization and dilation.

Although the geometry might differ depending on the timing after myocardial infarction, Factor 4 often causes Factor 3, and leads to Factor 1, which interferes with leaflet coaptation and results in MR, especially when Factor 2 is present. In addition, another factor should be described:

· **IMR Factor 5** Tenting (tethering) of not only the anterior leaflet but also the posterior one is now also known about; the latter is often seen in patients after mitral annuloplasty (MAP)[13,14] or even before (**Figure 2**)[15]

Evolution of Surgical Treatment for IMR

In those days, when geometric etiology of IMR was uncertain, when a patient became too sick with whilst undergoing their current medical treatment, surgery such as coronary bypass surgery (CABG) or CABG with mitral valve replacement (MVR) was often a choice[16] In the discussion of MVR vs MAP, some series gave a favorable impression for MAP[17–21] and some others favored MVR[22] but either way, the long-term results were less than satisfactory for both. Although mitral valve repair theoretically gives better postoperative LV function than MVR does, care should be taken for those patients who have had MVR because they might have possibly had had more damaged LV preoperatively. A proper comparison between MVR and MAP, such as a prospective and randomized study, is very difficult and even unethical for the ill patients in these categories.

At that point, the indication for MVR was similar to that in patients with organic MR, such as myxomatous or rheu-

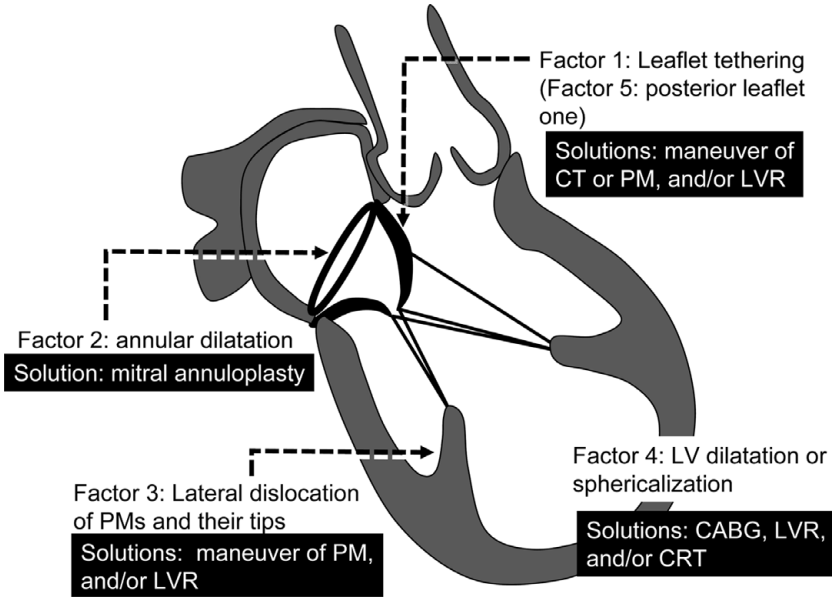

Figure 1. Geometric abnormalities of ischemic mitral regurgitation and their surgical solutions. CT, chordate tendineae; PM, papillary muscle; CABG, coronary bypass surgery; LVR, left ventricular restoration surgery; CRT, cardiac resynchronization treatment.

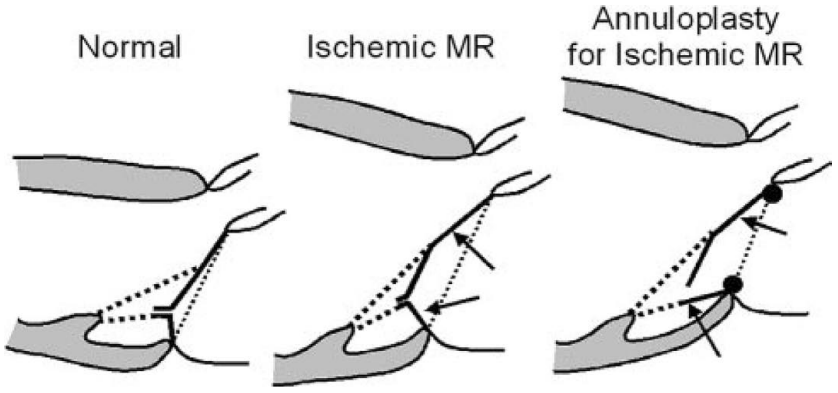

Figure 2. Geometry in the tethering of the posterior mitral leaflet (from Zhu et al. *Circulation* 2005; **112**(9 Suppl)**:** I-396 – I-401).

matic MR. Thus, if the MR was not severe, CABG alone was often done and as a result, MR tended to reoccur and the patient required a repeat admission to the hospital. When the MR was severe, MVR in addition to CABG was done, and the results of the operation were worse than that for usual CABG or MVR.

As experiences increase in the 1990 s, MAP together with CABG as a treatment became more popular, especially aggressive (ie, down-sized) MAP, which used a smaller ring (eg, smaller for 2 sizes) than the anterior leaflet, as advocated by Bolling et al, and is widely accepted.[23,24] In fact, aggressive MAP ameliorated MR in many patients and its benefit on LV function was shown experimentally[25] and clinically.[26]

An indication for surgery shifted from severe IMR to moderate IMR, because moderate IMR can easily deteriorate to become severe IMR when the LV is dilated further and especially when the tenting (tethering) is strong.[27–29] Calafiore et al reported that mitral valve with a tethering height higher than 11 mm is hard to be repaired by using MAP alone.[30] In other words, additional procedures are necessary for the patients in this category.

As the understanding of abnormal geometry of the mitral valve, subvalvular apparati, and LV wall in IMR increased, several reparative methods have been developed (**Figure 3**).

For Dislocated PMs

Sling method to bring both PMs closer each other to correct lateral displacement of both papillary tips.[31]

Reapproximation of both PMs by pledgeted sutures for the same purpose as the above.[32,33]

These methods make sense when we think of the lateral dislocation of PMs and tips, if it does not impair the function of the LV wall between the PMs and if it does not induce ischemia of PMs.

For Tethering or Abnormal Position of Papillary Tips or Leaflets

Application of edge-to-edge repair as reported by Fucci et al for myxomatous MR.[34] The unique method helps the closure of leaflets without creating mitral stenosis, but it does not make a natural shape of the valve and long-term results might not necessarily be stable.

Extension of the anterior leaflet by pericardial patch.[35] This method might offer a practical solution to ameliorate IMR, but there remains a concern of valvular solution for ventricular disease.

Severing secondary chordate or strut chordate to ameliorate tethering of the anterior leaflet.[36,37] In some reports, the method did not impair LV function,[36] while in others it did.[38] As the secondary chordate plays a role to protect LV dimen-

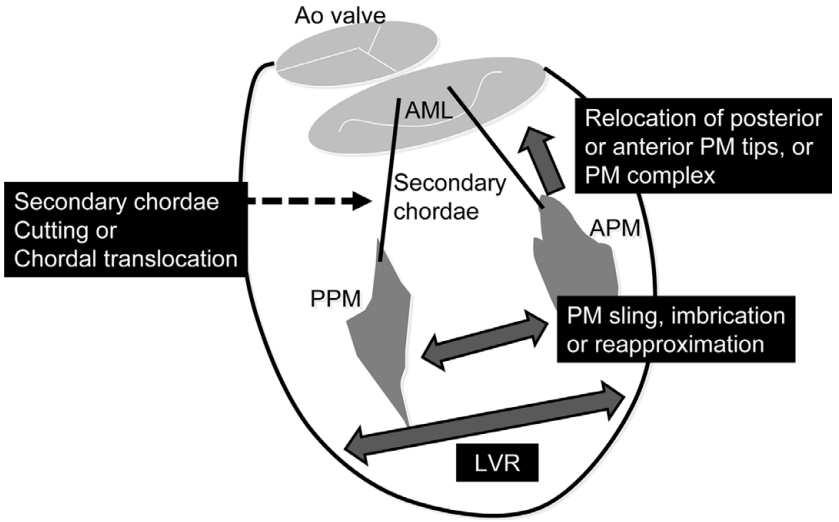

Figure 3. Surgical maneuvers for subvalvular apparati or the left ventricle. Ao, aortic; AML, anterior mitral leaflet; PM, papillary muscle; APM, anterior PM; PPM, posterior PM; LVR, left ventricular restoration.

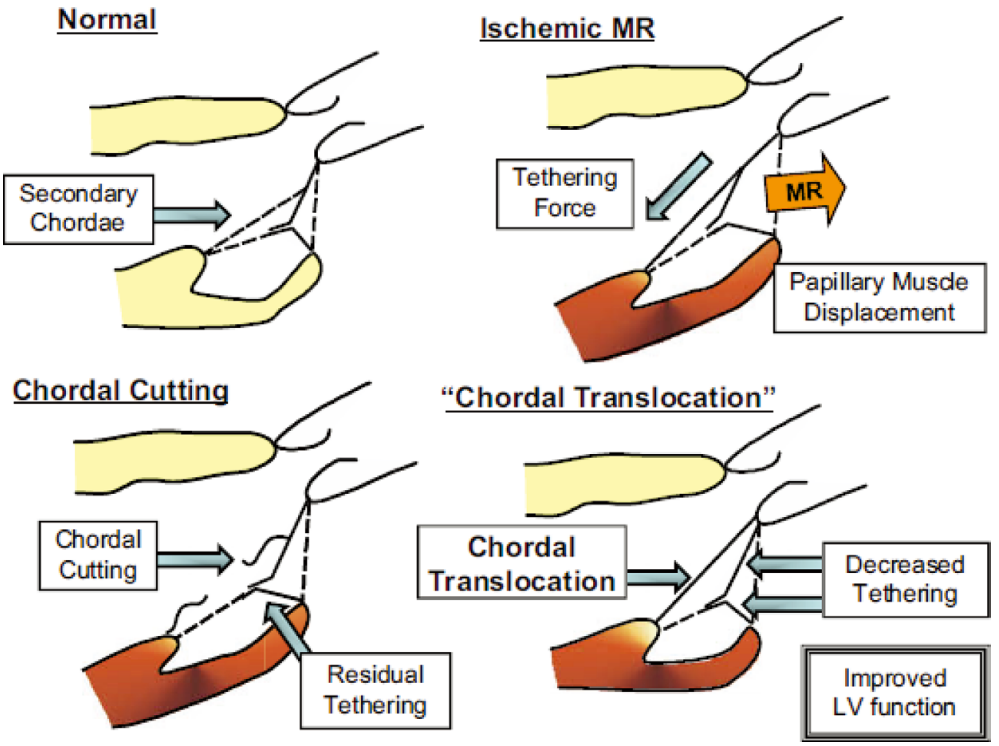

Figure 4. Significance of papillary tip relocation to the physiological *anterior* direction as seen in the chordal translocation method (from Masuyama et al. *J Thorac Cardiovasc Surg* 2008; **136:** 868–875).

sion and function, the chordal cutting method might impair LV function, at least under certain conditions.

Relocation of the papillary tips by sutures toward posterior mitral annulus,[39] commissure or anterior annulus[38] The method might offer a more efficient solution for IMR. Too much tension to the papillary tips might be less beneficial or even harmful for the PMs and/or LV. The issue might have to be investigated further.

Sandwich plasty where papillary tips for the anterior leaflet and the posterior one are sandwiched.[40]

The method has different approaches from the above-described methods. So far, no study has been conducted to focus on the geometry of PM tips for the anterior or posterior leaflet in the setting of IMR. If it has a different mechanism from other methods, this method could be used concomitantly with others.

In addition, further improvement was attempted.

Combined Methods to Repair the Leaflet/PMs/LV

Relocation of the tip of the PM complex, which was made by reapproximating both PMs.[41] The method increases mitral coaptation, but bringing the man-made single PM toward the mitral annulus seems to be too unnatural, and further studies should be conducted.

"Chordal Translocation" where the secondary chordate were transected and the continuity of papillary tips and

anterior mitral annulus was reconstructed by Gore-Tex sutures.[38,42,43] This method is in parallel with the natural structure and function of the mitral valve, but it is a slightly more complex procedure and might require some experience when conducting it, especially in order to prevent aortic regurgitation. Langer and Schäfers reported the anterior relocation of each papillary tip without cutting the secondary chodae.[44] This method is intriguing, but potential issues of over-tension to the PMs/tips and diastolic tethering might remain.

Many methods to relocate or pull up the PM tips require posterior direction, which does not effectively improve tethering of the posterior leaflet. Masuyama et al showed that chordal translocation, which pulls PM tips anteriorly (ie, the direction of the secondary chordate and the "stress line" toward the mid-anterior annulus), improved tethering of the posterior leaflet (**Figure 4**).[42,43] Further investigation is warranted experimentally and clinically.

MAP is an established and old technique, but it keeps evolving. In the early days, a flexible, semi-rigid, or rigid ring was used in the MAP procedure at a surgeon's preference. As the importance of shorteing the annulus in a septo-lateral direction was reported by Miller's group,[45] rigid or semi-rigid rings gradually became a preferred choice in terms of use. Moreover, new rings for MAP, which take mitral geometry in IMR into consideration, is now available in Western countries with promising results.[46,47] Long-term results will hopefully be reported in the near future.

For Abnormal LV Wall Geometry/Motion

CABG for the LV wall with ischemia and reversible dysfunction.

The importance of coronary revascularization is an eastablished concept and can be applied to patients with IMR. This is true, especially when the amount of residual myocardium is limited.

Left ventricular restoration (LVR) for the LV wall with dyskinesis or large akinesis.[48–54]

When the LV is too dilated or compromised, CABG alone[55] or CABG with MAP alone often is not effective enough to improve the patient outcome.[51,52,56] For these patients, LVR might be indicated. For LVR, Dor surgery, septal-anterior ventricular exclusion, partial left ventriculectomy, or Overlapping surgery can be conducted depending on the location of the lesion.[57] Preservation of the LV apex or its part when the LV apex is aneurysmal, seems beneficial theoretically,[58] experimentally[59] and clinically.[49] The concomitant application of MAP might give favorable results long term.[54,57] A combination of LVR with subvalvular/valvular apparati seems more efficient to stabilize the valve.[33,43,53] Care should also should be taken to decrease ischemic time or cardiopulmonary bypass time because the patients in this category have poor LV and/or have a poor general condition.

For more details regarding LVR, refer to the related articles in this special issue.

CRT if there is dyssynchrony.[60]

CRT after or concomitant with surgery for IMR often offers a valuable adjunct to further improve LV function. When LV dissynchrony becomes evident after surgery (especially LVR), CRT is worthwhile to consider as a treatment.[61]

For Lethal Arrhythmias Such as VT/VF

Coronary revascularization by CABG.

Cryoablation for the LV lesion when LVR is performed. Ideally, preoperative or intraoperative mapping of the LV electorical condition should be done, but it is time consuming and might be harmful because it prolongs operation or ischemic time. Empirically, intraoperative cryoablation for the myocardium near the ischemic scar without electorical mapping offers an effective treatment for VT or VF.

ICD when indicated.

CRT-D if both ICD and CRT are indicated.

For details of ICD/CDT, please refer to the related article in this special issue.

The above procedures and/or their combination are currently selected according to experiences and policies in each hospital or as a preference for a surgeon. As experiences/data accumulate, proper indication/selection/combination of the methods will be gradually established. The problem is that regardless of the surgical methods used, when residual myocardium is too little and therefore when residual LV function is not enough, prognosis of the patient might be dismal, and they might need LVAS or a transplant.

Even though the sick patients survive, if their postoperative LV function is poor, the LV will be spherical in shape and MR might recur. In some patients, MVR with preservation of chorde and PM might possibly be more reliable and safer.

IMR teaches us that the mitral valve is an important part of the LV, and LV power and geometry will determine the results.

Non-Ischemic, Functional MR

This type of MR often develops in patients with idiopathic dilated cardiomyopathy.[23] Mechanism of MR development is similar to that of IMR. Surgical treatment for the MR is similar to that for IMR, except for CABG. In terms of LVR surgery for non-ischemic dilated cardiomyopathy,[57] care should be taken in terms of considering the differences of the LV wall with lesions compared with the LV wall without lesions, as the former might be smaller and that the LV muscle near the "border zone" tends to be more fragile than when the LV is treated with IMR.

Among non-ischemic FMR, dilated cardiomyopathy secondary to sarcoidosis[62] or LV non-compaction,[63] might have a more discrete lesion as compared to idiopathic dilated cardiomyopathy. Thus, FMR caused by sarcoidosis or LV non-compaction can potentially become a good candidate for surgical repair.

Summary

Non-transplant surgical treatment for functional MR has made remarkable progress over the past decades, and in many patients, reparative surgery can be conducted successfully for ischemic/non-ischemic FMR. However, the surgery still carries a relatively high risk in sick patients, and the volume and function of the residual LV myocardium remains an issue. Further investigation is necessary to make the reparative surgery less invasive, more reproducible and more stable long term. Also, efforts to increase the working myocardium will be beneficial.

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