# Papillary muscle approximation in mitral valve repair for secondary MR

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**Abstract:** Ischemic mitral regurgitation (IMR) is a complex disorder occurring after a myocardial infarction and affecting both the mitral valvular and subvalvular apparati. Several abnormalities can be detected in IMR as annular dilatation, leaflet tethering with impaired coaptation and papillary muscle (PM) displacement along a posterior, apical or lateral vectors. Treatments available include, beside myocardial revascularization, mitral-valve repair or chordal-sparing replacement. Repair is normally achieved downsizing the mitral valve annulus with a rigid or semirigid ring. However, considering the involvement of the subvalvular apparatus, techniques addressing the PM have been developed. The rationale at the basis of this strategy relies in the possibility to reduce the interpapillary muscle distance restoring the geometry of the left ventricle (LV) and ultimately resolving the leaflet tethering at the basis of IMR. Subvalvular apparatus surgical approaches include the papillary muscle approximation (PMA), surgical relocation and PM sling. Improved outcomes in terms of postoperative positive left ventricular remodeling and recurrence of mitral regurgitation have been reported, but more investigations are required to confirm the efficacy of subvalvular apparatus surgery. Application of finite element analysis to improve preoperative and intraoperative planning and achieve a correct and durable repair by means of subvalvular surgery is an exciting new avenue in IMR research.

**Keywords:** Mitral valve repair; ischemic mitral regurgitation (IMR); papillary muscle approximation (PMA); restrictive annuloplasty

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#### Introduction

Ischemic mitral regurgitation (IMR), is an acquired dysfunction of valve mitral motion, consequent to a myocardial infarction (MI). Left ventricular distortion and remodelling after MI originate a set of complex geometric alterations directly affecting the profile and function of both the valvular and subvalvular apparatus. The following resulting abnormalities can be detected in IMR: annular dilatation, leaflet tethering with impaired coaptation and papillary muscle (PM) displacement along a posterior, apical or lateral vectors (1).

Unlikely to primary diseases such as rheumatic or myxomatous degeneration, IMR is always associated to coronary artery disease. Considering its pathological dependence on MI, different degrees of valve incompetence might occur according to the extent of the ischemia and to several other factors as ventricular afterload and dissynchrony. Wider areas of necrosis or significant post infarction geometrical remodeling might lead to

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moderate to severe mitral regurgitation requiring surgical correction. IMR carries a significant burden in terms of health economical expenditure and resources exploitation especially considering its chronic course and slowly progressive critical evolution (2).

No medical treatment is available to solve moderate and severe IMR, so beside an effective primary prevention strategy to avoid MI, the development of IMR requires a surgical decision in a reasonably short time. Long-term prognosis in these cases is unfavorable with a perioperative mortality among elderly patients and patients with severe left ventricular dysfunction of about 30% (3-6). Recently, clinical research efforts have been focused on patients with moderate and severe IMR requiring combined mitral surgery and CABG with the aim to prevent reoperation for mitral regurgitation recurrence and identify an adequate operative strategy addressing the subvalvular apparatus to improve the long-term durability of the repair (7).

Surgical treatment in combination with cardiac resynchronization is indicated in patients with severe IMR as no more responsive to medical therapy. For these patients ACC/AHA guidelines recommend consideration of mitralvalve repair or chordal-sparing replacement, however, do not indicate which is the best treatment or when to use one approach or the other (8,9). Current data from observational studies are inconclusive and do not provide a certain answer regarding the superiority or advantage of one treatment over the other. If on a side mitral repair has been shown to have lower perioperative mortality, replacement revealed better long-term outcomes with a lower risk of mitral regurgitation recurrence, a condition that can compromise the postoperative outcome of the patients leading to heart failure, atrial fibrillation, and in-hospital readmission (3). The unclear orientation of the guidelines has generated substantial confusion in the surgical practice and the lack of randomized controlled clinical trials able to adjust for baseline differences and confounding factors is additionally complicating the understanding of the best strategy to adopt. Indeed, in the majority of the currently published observational studies patients are not stratified or selected to ensure equipoise and patients who received mitral chordal-sparing replacement generally tended to be older and have more coexisting comorbidities than those who underwent restrictive mitral repair.

For long time the debate among the heart teams regarding the benefit of associating restrictive mitral annuloplasty (RA) to CABG in patients with moderate IMR has been indecisive. The guidelines were centered on two opposing trends (7). Some believe that patients with moderate IMR can be served by CABG alone as the revascularization may improve regional and global left ventricular function with subsequent benefit on the adverse PM displacement, restoration of subvalvular apparatus function and normalization of leaflet tethering. Additionally, from the technical standpoint, the combination of CABG procedure and mitral repair would inevitably extend the duration of aortic cross-clamping, cardiopulmonary bypass and of the overall intervention with associated increased perioperative risk (4,10). On the contrary, other health providers consider that RA combined with CABG is able to prevent the risk of persistent IMR as directly addressing the annulus and promoting the improvement of left ventricular remodelling and function (1,11). Therefore, patients might have a lower risk of repeat surgery and re-hospitalization for heart failure.

## Diagnosis and considerations of geometric parameters conditioning surgery of IMR

The diagnosis of IMR is generally based on clinical and echocardiographic findings. Diagnostic criteria rely on dedicated imaging (TTE, TEE, CT scan and MR), which holds a sensitivity and specificity of more than 80% (12). However, this should not replace the clinical judgment for diagnosis in the individual patient, especially in the first stage of myocardial infarction. Appearance of new cardiac murmur occurs in 10% to 50% of the patients developing severe or moderate IMR after MI, respectively. Dedicated investigations normally lead to the identification of other elements as highgrade and proximal coronary artery lesions with or without previous stenting in the first few hours after an acute MI, atrial fibrillation, decrease of left ventricular function, enlargement of left ventricular chambers and increased left atrial pressure (13). Known complications include severe cardiac failure as well as renal and pulmonary dysfunction, especially in cases of increased pulmonary pressure in which surgical intervention has been delayed. Extension of MI in the lateral zones has been associated with an increased risk of left ventricular dysfunction, heart failure and death, especially in the elderly. Echocardiography, CT and more recently systematic magnetic resonance imaging (MRI) of the heart may reveal geometrical mitral abnormalities in all patients [end-diastolic diameter, end-systolic diameter, end-diastolic volume index, endsystolic volume index (ESVI), left ventricular ejection fraction, systolic sphericity index (SSI), diastolic sphericity index (DSI), myocardial performance index, tenting area, effective regurgitant orifice area, regurgitant volume, regurgitant

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fraction, coaptation height, coaptation length, coaptation distance, AML tethering angle, PML tethering angle]. Refined parameters of imaging may be used for the evaluation of the feasibility of surgery and to identify the correct surgical strategy [posteromedial papillary muscle-wall motion score index (PMPM-WMSI), anterolateral papillary muscle-wall motion score index (ALPM-WMSI) and WMSI] (14).

Mitral leaflet tethering is the main alteration in IMR determining inappropriate traction of both leaflets of the valve. The degree of tension exerted on the leaflets mainly depends on the entity of PMs displacement, which is the actual cause of the impaired coaptation and valve regurgitation observed in IMR. Tethering can have a symmetric or asymmetric pattern reflecting the direction of PM displacement vector, the localization of myocardial infarction zone and the severity of global ventricular dysfunction (15,16). Normally PMs provide a number of chordae that are attached to both leaflets, anterior and posterior, but with a substantial difference in case of symmetric or asymmetric tethering shape. Lateral and apical vector displacement of PMPM determines a symmetric traction of both leaflet with consequent mitral regurgitation characterized by a central jet. This pattern is associated to very dilated left ventricle (LV) chambers, systolic and DSI markedly and equally increased and similarly augmented alfa and beta angles of mitral leaflet tethering. Many patients have also an anterior myocardial infarction with lateral extension and significantly abnormal WMSI. In the asymmetric shape, posterior vector is predominant and left ventricular distortion is more evident with a more significant increase in DSI over the systolic. The traction forces related to the posterior vector displacement of PMPM exert greater tenting action on the posterior cusp of mitral valve resulting in an eccentric jet at echocardiography. The entity of beta angle of mitral leaflet tethering is predominantly altered in comparison to the alfa angle supporting the idea of a higher degree of left ventricular distortion. Studies have demonstrated the benefit of a combined approach including subvalvular apparatus repair and mitral annuloplasty especially in patients with involvement of the posterior wall after myocardial infarction rather than antero-lateral wall impairment and with not dramatically impaired WMSI (17).

#### Surgery

Several progresses have been made since Alain Carpentier described "the French correction" in mitral valve repair demonstrating the benefit of surgery in patients who had type II structurally normal mitral valve, systolic restricted leaflet motion on the remaining leaflets (type IIIb) and some degree of annular dilatation (functional type I) (18). However, the surgical dogma that mitral valve reconstruction is "always practicable" has been dispelled and the surgical approach for IMR has been open to comparisons and criticisms. The continuous progress and refinement in in echocardiography-based imaging brought novel valvular measures (e.g., tenting area, coaptation distance and interpapillary muscle distance) and ventricular measures (e.g., LVESVI, sphericity index and wall motion score index) as possible predictors of recurrent mitral regurgitation(14). On these bases, many surgeons explored the treatment of the subvalvular apparatus as a potential approach to reestablish mitral valve function in moderate and severe IMR. Rama firstly performed the approximation of PMPM to ALPM combined with RA in a patient with proximal coronary lesions who underwent coronary revascularization (19). Shortly afterwards Kron and Hvass have been described the techniques of PM relocation and PM sling, respectively (20,21).

The current approach to IMR include restrictive annuloplasty with a rigid or semirigid ring to downsize the annul diameter (7). Association with subvalvular procedures has been successfully performed (5,20,21). The rationale at the basis of this strategy relies in the possibility to reduce the IPD restoring the geometry of the LV and ultimately resolving the leaflet tethering at the basis of IMR (22). Careful knowledge and attention to PM functional anatomy is required and PM vascular supply (23) needs also to be taken into account when performing this type of surgery. The anatomical variability of PM has been described within a comprehensive classification which foresees 5 patterns in accordance to the PM shape and number of heads (24). Subvalvular apparatus surgical approaches include the papillary muscle approximation (PMA) (5,19), surgical relocation (20,25), PM sling (21). Type I and II PM are approximated using a CV-4 Gore-Tex suture (W. L. Gore and Associates, Flagstaff, Ariz) placed at the head of each PM. In type III, IV or V approximation is performed with a 4 mm Gore-Tex tube (W-L Gore and Associated, Flagstaff, Ariz) encircling the bodies of PMPM and ALPM. In the presence of two independent heads, both PMPM are approximated to minimize mitral valve tenting (26). In the relocation technique the ALPM and PMPM are fixed to the anterior and posterior trigones, respectively (20). Particular attention is recommended to the evaluation of the chordal organization. Normally, the PMPM gives rise to chordae located to scallop P2 and P3 of the posterior leaflet, while

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the antero-lateral papillary muscle originate the chordae directed to anterior leaflet, responsible for the development of the "seagull sign" and respective tenting. Intraoperative transesophageal echocardiography is a crucial aid for the success of PM surgery. Attempts have been made to achieve the benefits of mitral valve repair or replacement with the use of less invasive methods (27). Additionally, considering the need for multivessel revascularization in IMR patients, approaches involving hybrid surgical and percutaneous revascularization associated to mitral valve treatment are being explored (28). However, these approaches still require additional investigations and extensive validation as might result in incomplete revascularization or less durable correction of mitral regurgitation after the procedure.

# Results from a randomized clinical trial on subvalvular apparatus surgery

The results of our 5-year randomized controlled clinical trial, designed to compare patients who underwent either combined PMA and RA or undersized valve repair alone, advanced our understanding of the relative benefits of adding subvalvular mitral repair to isolated restrictive annuloplasty in the management of severe IMR (5). We observed significant between-group difference in the rankbased assessment of left ventricular reverse remodeling at 5 years. Although the LVEDD significantly improved in respect to baseline in the both the groups during two years follow-up, a further improvement after the second year in the combined PMA group was observed (5). Similarly, mortality after the second year was significantly higher in the isolated restrictive valve repair group. Early 30-days cardiac mortality was lower in the PMA in respect to annuloplasty-only group (4.2% vs. 6.2%, respectively), however the sample size enrolled for this study had insufficient power to establish definitive conclusions to indicate which of these interventions is superior on survival (5). The percentage of death revealed in our report was consistent with the results that have been published in CTS-Net trial for the treatment of IMR (3,4,6).

However, the major finding of our trial was the high rate of mitral regurgitation recurrence, which was mostly graded as moderate but remained a disappointing complication in patients undergoing restrictive mitral-valve repair. During the 5-year follow-up period, 55.9% of patients in the RA group had moderate or severe regurgitation, as compared with 27% in the PMA group (5). The more limited durability of the repair achieved with the annuloplastyonly approach also justifies the occurrence of adverse events as heart failure, atrial fibrillation, repeated surgery and rehospitalizations in this group. The findings of the Minnesota Living with Heart Failure questionnaire were not different between groups if analyzed within the first 2 years after surgery, but reflected the occurrence of these adverse clinical events in last 3-year follow up (5).

Interestingly, patients in the PMA group who did not have recurrent mitral regurgitation experienced a significant reverse remodeling, testifying that negative remodeling of left ventricular chambers is the real Achilles heel for the success of the intervention. Positive remodeling and improvement of PM dyssynchrony and wall motion score index are related to the completeness of myocardial revascularization (5,17).

Our previous analysis is important to identify the predictors of recurrent mitral regurgitation and to individuate the best candidates for the combined approach of PMA and restrictive annuloplasty. An important area of research to further improve preoperative and intraoperative planning is the application of finite element analysis (FEA) to establish the correct measures (tenting area, antero-posterior annulus diameter and interpapillary muscle distance) to achieve an adequate and durable repair in the context of IMR.

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#### Footnote

*Conflicts of Interest:* The authors have no conflicts of interest to declare.

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