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Subvalvular techniques to optimize surgical repair of ischemic mitral regurgitation

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Abstract

Purpose of review—Surgical treatment of ischemic mitral regurgitation with reduction annuloplasty is the current standard of practice, yet recurrence rates approaching 30% limit the benefits of repair in this subset of patients. In an effort to improve outcomes, attention has turned to understanding the contribution of leaflet tethering in this disease process. Subvalvular techniques to alleviate leaflet restriction have recently been incorporated into methods of repair.

Recent findings—Parameters of left ventricular remodeling have been quantified as risk factors for recurrence of mitral regurgitation following reduction annuloplasty. Papillary muscle relocation restores the physiologic configuration of the subvalvular apparatus, and results in significantly reduced rates of recurrent mitral regurgitation and adverse cardiac events over time. Secondary chordal cutting or reimplantation results in significantly increased leaflet mobility, decreased severity of recurrent mitral regurgitation, and improved reverse remodeling without adverse effect on left ventricular function.

Summary—A superior repair with decreased recurrence of mitral regurgitation and enhanced reversal of left ventricular remodeling is possible when subvalvular techniques are combined with traditional ring annuloplasty. Further understanding of preoperative parameters that predict disease recurrence and inclusion of concomitant subvalvular techniques in this subset of patients will be the next major advance in this field.

Keywords

chordal cutting; chordal reimplantation; ischemic mitral regurgitation; papillary muscle relocation; subvalvular repair

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Conflicts of interest

There are no conflicts of interest.

INTRODUCTION

Ischemic mitral regurgitation is a dynamic process resulting from progressive dilatation of the left ventricle and mitral annulus after transmural infarction. Historically, patients were treated with mitral valve replacement without chordal preservation. Outcomes were dismal, likely due to disruption of valvular-ventricular continuity and resultant left ventricular dysfunction. The focus then shifted to mitral valve repair, and this has remained the mainstay in the treatment of ischemic mitral regurgitation. To address Carpentier type I mitral regurgitation caused by annular dilatation, annuloplasty is typically performed with a ring that is 1–2 sizes smaller than the normal ring size based on anterior leaflet height and intertrigonal distance. This technique of reduction annuloplasty is the current universal treatment of choice for ischemic mitral regurgitation, and outcomes have improved since the era of mitral valve replacement.

However, recurrence of moderate-to-severe mitral regurgitation occurs in up to 30% of patients within 6 months of repair [1]. This observation can be explained by consideration of the subvalvular apparatus; namely, the effects of left ventricular dilatation, papillary muscle displacement toward the apex, and tethered mitral leaflets on overall valve competence. This component of Carpentier type IIb mitral regurgitation due to leaflet restriction is not corrected and is actually worsened by reduction annuloplasty [2]. As the mobile posterior annulus is shifted anteriorly during reduction annuloplasty, tethering of the posterior mitral leaflet is significantly augmented. The tethered anterior leaflet must be able to coapt with the often essentially fixed posterior leaflet and cover the entire annular area to establish efficacy of repair. With even slight ventricular dilatation and papillary muscle displacement following reduction annuloplasty, the anterior leaflet becomes further restricted and unable to maintain durability of repair, resulting in recurrent mitral regurgitation.

It is clear that a subset of patients with significant preoperative mitral leaflet restriction will benefit from concomitant procedures that address altered subvalvular mechanics. Identifying those patients who will benefit from these procedures remains the current challenge in this field. We estimate that subvalvular repair may be necessary in 10–20% of patients with ischemic mitral regurgitation. Reported techniques target all aspects of the subvalvular apparatus, including the chordae tendineae, papillary muscles, and left ventricular free wall, in an effort to restore physiologic configuration and function of this integral component of the mitral valve. Improving the long-term success of repair will be critical as chordal-sparing mitral valve replacement becomes an attractive alternative treatment option.

RISK FACTORS FOR RECURRENT MITRAL REGURGITATION

Several recent studies have identified preoperative parameters that are associated with recurrent mitral regurgitation after reduction annuloplasty. A variety of mitral leaflet characteristics have been quantified as risk factors in this process. Tethering angle is measured as the angle between the mitral annulus and the anterior or posterior leaflet and has been proposed as one such factor. Rates of recurrent mitral regurgitation are directly related to anterior leaflet tethering angle, with higher rates of recurrence observed in patients with increased anterior leaflet tethering angles. Specifically, an anterior leaflet tethering

angle greater than 36.9° is associated with significantly higher rates of recurrence after reduction annuloplasty [3[¶]].

Excursion angle is measured as the difference between leaflet configurations during systole and diastole and is a quantitative measure of leaflet restriction. An anterior leaflet excursion angle less than 35° is also a significant predictor of recurrent mitral regurgitation [3[¶]].

In addition to increasing the tethering angle, secondary chordae of the anterior mitral leaflet play an important role in reducing distal leaflet mobility, and therefore coaptation with the posterior leaflet after reduction annuloplasty. Severe distal anterior leaflet tethering is associated with recurrence of mitral regurgitation [4].

Posterior leaflet restriction also becomes a critical factor in postoperative mitral valve competence, as tethering of this leaflet is worsened after reduction annuloplasty. An increased preoperative posterior leaflet tethering angle is a known risk factor for recurrent mitral regurgitation [4].

Coaptation length refers to the distance that the mitral leaflets are in contact during systole, and is normally greater than 8mm. Coaptation depth (or tenting height) refers to the distance from the mitral annulus to the line of leaflet coaptation during systole, and is normally less than 6mm. Tenting area refers to the region between the mitral annulus and the leaflets during systole. These values are all altered in ischemic mitral regurgitation due to leaflet tethering, and disease recurrence after reduction annuloplasty is strongly associated with preoperative abnormalities in these values [4].

Certain dimensions of the mitral annulus and left ventricle have been identified as risk factors for recurrence of mitral regurgitation after reduction annuloplasty. Left ventricular remodeling results in papillary muscle displacement in the apical and posterior direction, causing leaflet restriction and Carpentier type IIIb mitral regurgitation. Dilatation of the left ventricle also leads to dilatation of the mitral annulus, resulting in Carpentier type I mitral regurgitation. This worsening mitral regurgitation leads to increased volume overload and further left ventricular remodeling in a progressive cycle. Increased mitral annular area is, therefore, a surrogate measure of severity of ventricular dilatation, and is strongly predictive of recurrent mitral regurgitation after reduction annuloplasty [5[¶]].

Increased left ventricular end systolic volume, a marker of ventricular dilatation, has been identified as a risk factor for recurrence of mitral regurgitation after reduction annuloplasty [5[¶]]. Left ventricular sphericity index, measured as the ratio of the longaxis length to the short-axis length, is a similar marker of ventricular dilatation and is a prognostic indicator of disease recurrence [4]. Left ventricular end diastolic index, measured as the left ventricular end diastolic diameter divided by body surface area, has been found to correlate with recurrence, with values exceeding 3.5cm/m^2 significantly associated with recurrent mitral regurgitation and decreased postoperative median survival after reduction annuloplasty [6].

SUBVALVULAR TECHNIQUES OF REPAIR

An unacceptable rate of recurrent mitral regurgitation following reduction annuloplasty and recognition of anatomical risk factors for disease recurrence have prompted the inclusion of the subvalvular apparatus into techniques of repair. Papillary muscle relocation to alleviate leaflet restriction was first reported one decade ago. The original technique consisted of passing a 3–0 prolene suture through the fibrous tip of the posterior papillary muscle and then through the mitral annulus immediately posterior to the right fibrous trigone prior to reduction annuloplasty. In the initial study, follow-up echocardiography revealed restoration of a more physiologic configuration of the relocated posterior papillary muscle, and no patient had recurrence of mitral regurgitation 2 months after repair [7]. There were no mortalities, and relocation of the papillary muscle, easily visualized through the left atriotomy, was identified as a safe and simple additional procedure.

These encouraging results prompted revisions in techniques of papillary muscle relocation, including a sling to anchor the bases of the papillary muscles together [8] and direct approximation of the tips of the papillary muscles together [9]. Years after papillary muscle relocation, the majority of patients in these studies are free from recurrent mitral regurgitation with evidence of reversal in left ventricular remodeling and improvement in ejection fraction, and most have significant improvement in New York Heart Association functional class. One recent study highlighted the impact of papillary muscle approximation on posterior leaflet tethering, which normally worsens following reduction annuloplasty. However, this augmented restriction was found to be significantly decreased in patients who underwent papillary muscle approximation [2*].

Last year, results of the first retrospective study comparing outcomes after reduction annuloplasty alone vs. concomitant papillary muscle relocation were published. In this procedure, both papillary muscles were realigned closer to the mitral annulus by passing a CV-4 Gore-Tex suture through the head of each papillary muscle and through the respective ipsilateral mitral annulus. Postoperatively, patients who underwent this combined procedure had significantly decreased mean tenting area and coaptation depth as well as significantly decreased left ventricular end systolic and end diastolic diameter over a mean follow-up of 32 months, which resulted in a significant decrease in recurrent mitral regurgitation throughout the study. There were no differences in early or late mortality, and patients who underwent papillary muscle relocation had a significant decrease in the occurrence of late cardiac events [10**]. Taken together, these results suggest that papillary muscle relocation is a safe and effective adjunctive procedure to decrease the rate of recurrent mitral regurgitation after reduction annuloplasty.

The next step will be to distinguish those patients who will derive maximal benefit from concomitant procedures on the subvalvular apparatus. In a report published this year, a subset of patients undergoing reduction annuloplasty for ischemic mitral regurgitation who were found to have significant left ventricular dilatation and increased tethering angles of both anterior and posterior mitral leaflets were selected to undergo a concomitant subvalvular procedure. The technique consisted of papillary muscle approximation and suspension to bring the papillary muscles in closer proximity to each other and to the mitral

annulus, as well as left ventricular restoration to exclude the dysfunctional region of infarction. One month after repair, tethering angles were reduced in both groups, and no patient had recurrent mitral regurgitation. However, 1 year after surgery, bileaflet tethering angles were significantly more increased in the group that did not undergo subvalvular repair, and recurrent mitral regurgitation occurred only among patients in this group [11^{***}]. Based on these results, we can conclude that incorporating the subvalvular apparatus into methods of repair impedes further left ventricular remodeling, papillary muscle displacement, leaflet restriction, and recurrent mitral regurgitation in patients with severe preoperative left ventricular dilatation and mitral leaflet tethering. We can also conclude that we have not perfected the identification of those patients who will depend on concomitant subvalvular procedures for a durable repair.

Concomitant procedures involving the chordae tendineae have also been reported in attempts to mitigate leaflet restriction. Chordal cutting is one such procedure, which has been met with resistance due to the potential for disruption of valvular-ventricular continuity and concern for progressive left ventricular remodeling. However, these procedures target the secondary chordae and leave the basal and marginal chordae intact, thereby preserving valvular-ventricular continuity. In one recent study, addition of bileaflet secondary chordal cutting to reduction annuloplasty resulted in increased leaflet mobility, which significantly decreased the severity of recurrent mitral regurgitation. Importantly, reversal in left ventricular remodeling was observed without adverse effect on left ventricular function [5^{*}].

Severity of distal anterior leaflet tethering, mediated by secondary chordae, has been found to be a risk factor for recurrent mitral regurgitation after reduction annuloplasty. This tenting effect results in the characteristic seagull sign of the anterior leaflet in ischemic mitral regurgitation, and the angle between the two segments of the anterior leaflet is known as the bending angle. One group recently stratified patients with excessive tethering of the anterior leaflet, as measured by a bending angle less than 145°, to undergo concomitant cutting of all secondary chordae to the anterior leaflet from both papillary muscles. Compared with patients who underwent reduction annuloplasty alone, patients who underwent chordal cutting had significantly decreased recurrent or persistent mitral regurgitation and improved New York Heart Association functional class at a mean follow-up of 33 months. There were no deaths attributable to cardiovascular causes, and ejection fraction increased to a more significant degree after chordal cutting [12^{*}].

To preserve all aspects of the subvalvular apparatus, chordal reimplantation has been reported as an alternative procedure to chordal cutting. In a recent retrospective study, patients with chronic ischemic mitral regurgitation and severe leaflet restriction underwent detachment and reimplantation of secondary chordae to a primary position along the anterior mitral leaflet. In addition to this cut-and-transfer technique, these patients underwent posterior papillary muscle relocation and a subset underwent infarct plication of the lateral left ventricular wall, maneuvers both intended to realign the displaced subvalvular apparatus to a more physiologic configuration under the mitral valve. The majority of patients were free of recurrent mitral regurgitation at 1 year, with echocardiographic and clinical findings revealing a significant improvement in ejection fraction and New York Heart Association functional class at follow-up [13^{***}]. Based on these results, chordal procedures represent a

valid option in our current armamentarium of concomitant subvalvular techniques in the treatment of ischemic mitral regurgitation.

CONCLUSION

Ischemic mitral regurgitation is the result of chronic left ventricular remodeling after transmural infarction. Left ventricular dilatation leads to mitral annular dilatation and mitral leaflet restriction. It is logical that separate mechanisms of disease deserve separate operative interventions. In certain situations, it is becoming increasingly apparent that overall long-term outcomes are substantially improved when repair of the subvalvular apparatus is incorporated into standard reduction annuloplasty. Immediate relief of valve tethering leads to decreased early recurrence of mitral regurgitation, allowing enhanced reversal of left ventricular remodeling, which prevents further papillary muscle displacement and leaflet restriction over time, thereby decreasing late recurrence of mitral regurgitation. Determination of those patients whose outcomes depend on these concomitant subvalvular techniques of repair will be the next important breakthrough in the surgical treatment of ischemic mitral regurgitation.

Acknowledgments

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REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- ▪ of outstanding interest

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KEY POINTS

- Ischemic mitral regurgitation occurs with the progressive left ventricular dilatation of ischemic cardiomyopathy, resulting in dilatation of the mitral annulus (Carpentier type I mitral regurgitation) and papillary muscle displacement and mitral leaflet restriction (Carpentier type IIIb mitral regurgitation).
- Reduction annuloplasty to correct mitral annular dilatation has been the standard operative treatment for ischemic mitral regurgitation, but the role of mitral leaflet tethering in this disease process and subvalvular techniques of repair to alleviate this tenting effect have only recently been established.
- Preoperative parameters that predict recurrent mitral regurgitation after reduction annuloplasty include increased anterior and posterior tethering angles, distal anterior leaflet tethering, coaptation depth, mitral annular area, left ventricular end systolic volume, and left ventricular end diastolic index, which may represent indications for interventions on the subvalvular apparatus at the time of repair.
- Subvalvular techniques of repair to alleviate mitral leaflet restriction target the chordae tendineae, papillary muscles, and left ventricular free wall, and have been shown to reduce recurrent mitral regurgitation, enhance reversal of left ventricular remodeling, and improve clinical outcomes.
- Identification of preoperative risk factors for recurrent mitral regurgitation and application of procedures to restore the subvalvular apparatus to a physiologic configuration will be required to improve the outcomes after reduction annuloplasty in a subset of patients with ischemic mitral regurgitation.