Mitral valve annuloplasty and anterior leaflet augmentation for functional ischemic mitral regurgitation: Quantitative comparison of coaptation and subvalvular tethering

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Objective: Although restrictive mitral annuloplasty (RMA) has been the preferred surgical treatment of functional ischemic mitral regurgitation (FIMR), some patients with severely dilated left ventricles will experience recurrent mitral regurgitation (MR). Consequently, new surgical strategies have been entertained to compensate for severely dilated ventricles by maximizing coaptation and reducing subvalvular tethering. Anterior leaflet augmentation (ALA) with mitral annuloplasty has been theorized to meet these goals. We compared the mechanistic effects of RMA and adjunct ALA in the setting of FIMR.

Methods: Mitral valves were mounted in a clinically relevant left heart simulator. The tested conditions included control, FIMR, RMA, and true-size annuloplasty with either a small or large ALA. The A2-P2 leaflet coaptation length, MR, and strut and intermediary chordal forces were quantified. All repairs alleviated the MR. The coaptation length was significantly increased from FIMR to RMA, small ALA, and large ALA ($P < .001$). Between repairs, a large ALA created the greatest length of coaptation ($P < .05$). Tethering forces from the posteromedial strut chordae were reduced from the FIMR condition by all repairs ($P < .001$). Only a large ALA reduced the intermediate chordal tethering from the FIMR condition ($P < .05$).

Conclusions: A large ALA procedure created the greatest coaptation and reduced chordal tethering. Although all repairs abolished MR acutely, the repairs that create the greatest coaptation might conceivably produce a more robust and lasting repair in the chronic stage. A clinical need still exists to best identify which patients with altered mitral valve geometries would most benefit from an adjunct procedure or RMA alone. (J Thorac Cardiovasc Surg 2014;■:1-6)

Functional ischemic mitral regurgitation (FIMR) has been classified as a Carpentier type IIIb valvular dysfunction that results from postinfarction left ventricular (LV) remodeling.[1] This disease poses a significant clinical challenge, because FIMR severity is directly associated with patient mortality.[2] Although significant knowledge of FIMR and its physiologic effect exists, the surgical management of FIMR remains controversial.[3-5] Amid this controversy, restrictive mitral annuloplasty (RMA) with a complete rigid ring has been regarded as a preferred surgical repair.[3,6] Although typically effective, approximately 10% to 15% of patients presenting with severe LV dilation will develop recurrent mitral regurgitation (MR), have low rates of reverse LV remodeling, and exhibit poor survival.[7-10]

Consequently, new adjunct surgical strategies have been attempted to compensate for severely dilated left ventricles.[4] When performed with mitral annuloplasty, these adjunct strategies have aimed to further alleviate chordal leaflet tethering, improve leaflet mobility, and maximize leaflet coaptation. Anterior leaflet augmentation (ALA)[5,11] has been recently demonstrated to restore leaflet coaptation and mobility without the need to unnaturally restrict the mitral annulus.[10,11] Although preliminary studies have demonstrated the potential benefits of both RMA and ALA, little knowledge exists of what mechanistic improvements in valve function can be expected.

In the present study, we aimed to elucidate the functional and mechanical benefits of ALA with true-size mitral annuloplasty compared with isolated RMA in the setting of FIMR. ALA was performed with 2 pericardial patch sizes to further elucidate the potential effects of the procedural technique. We hypothesized that ALA will achieve leaflet coaptation comparable to that of RMA, while yielding significant improvements in leaflet tethering as measured by chordal forces.

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Abbreviations and Acronyms

- ALA = anterior leaflet augmentation
- FIMR = functional ischemic mitral regurgitation
- LV = left ventricular
- MR = mitral regurgitation
- MV = mitral valve
- PM = papillary muscle
- RMA = restrictive mitral annuloplasty

METHODS

In Vitro Simulator

The extensively studied Georgia Tech left heart simulator was used for the present study.[12] This in vitro model has been previously demonstrated to mimic the systolic mitral valve (MV) geometry,[12] leaflet coaptation, regurgitation, and anterior leaflet strain of healthy and chronic FIMR ovine models. In this model, ovine MVs were excised, mounted into the simulator, and tested using pulsatile left side heart hemodynamics.

Chordal Force Transducers

Miniature C-shaped force transducers have been used previously to quantify the tethering forces of the MV's chordae tendineae.[13] These strain gauge-based transducers were manufactured and tested within our laboratory. Calibration was performed before and after each experiment. The relationship between the calibrated load and transducer voltage output was linear, with a regression coefficient (R^2) of 0.98 to 1.00. The relative difference between the measured and true calibrated values (accuracy) was <2%. The smallest measurable tension was 0.01 N.[13] Before each experiment, these transducers were sutured directly to selected chordae without altering the chordae's native length. The section of chordae located between the transducer's measurement arms was bisected such that all tensile loading of the chord was transferred to the transducer.

MV Experimental Preparation

For the present study, fresh ovine hearts (n = 15) were procured from a local abattoir. The MVs were excised, preserving their annular and subvalvular anatomy. MVs with an anterior leaflet height of 20 to 25 mm, type I or II papillary muscles (PMs), and all leaflet chordae inserting directly into each PM were selected for experimentation. Selected MVs were sutured to the simulator's annulus using a Ford interlocking stitch. During MV suturing, care was taken to place each suture just above the MV's natural hinge and not through the leaflet tissue. Additionally, the normal annular–leaflet geometric relationships were respected, with the anterior leaflet occupying one third of the annular circumference and commissures aligned in the 2- and 10-o'clock positions. After annular suturing, the strut chordae inserting into the anterior leaflet (n = 2) and intermediary chordae inserting into the posterior leaflet (n = 2) were instrumented with chordal force transducers. After instrumentation, each PM was attached to the positioning control rods.

Experimental Protocol

After mounting each of the instrumented MVs within the simulator, the mitral annulus was conformed to the shape of a size 30 Physio Annuloplasty Ring (Edwards Lifesciences, Irvine, Calif). On establishing human pulsatile left heart hemodynamics (cardiac output, 5.0 L/min; heart rate, 70 bpm; transmitral pressure, 120 mm Hg), each PM was carefully positioned to establish the control MV geometry.[14] Mitral coaptation was inspected using echocardiography. The anterior leaflet spanned two thirds of the A2-P2 annular diameter, 5 to 6 mm of coaptation was achieved, and <1 mm tenting was observe. If the control valve geometry conditions had been successfully achieved, transmitral flow, left atrial and ventricular pressure, 3-dimensional echocardiography (Philips iE-33 Matrix, Phillips Healthcare, Andover, Mass), Doppler echocardiography, and chordal forces were acquired.

To simulate chronic FIMR due to inferior myocardial infarction, the valve annulus was asymmetrically dilated to 150% of the control valve area. The anterolateral PM was displaced 3 mm apically and 2 mm anteriorly, and the posteromedial PM was displaced 4 mm apically, 4 mm posteriorly, and 8 mm laterally. These changes were consistent with the data from chronic FIMR due to inferior myocardial infarction.[1] After establishing these conditions, all experimental measurements were acquired.

In the present study, 3 repair strategies were evaluated, including restrictive mitral annuloplasty (n = 15), true-size annuloplasty with a "small" ALA (n = 8), and true-size annuloplasty with a "large" ALA (n = 7). Restrictive and true-size mitral annuloplasty were simulated by conforming the simulator's annulus to a size 26 and size 30 Physio ring, respectively (Figure 1).

The ALAs were randomized and completed in 2 sizes using bovine pericardium lightly fixed in 0.5% glutaraldehyde. For the large ALA, the patch dimensions were 2.68 ± 0.25 cm long, 1.07 ± 0.10 cm high, and an area of 2.26 ± 0.36 cm^2. For the small ALA, the patch dimensions were 1.77 ± 0.10 cm long, 0.65 ± 0.14 cm high, and an area of 0.86 ± 0.29 cm^2. An incision was made near the base of the anterior leaflet and parallel to the mitral annulus. This created an oblong-shaped opening in the anterior leaflet to which the patch was sutured. The length of the incisions corresponded to the length of the desired patch dimensions. With either ALA repair, a concomitant true-size annuloplasty procedure was performed. The pericardial patch was positioned in place using 4 interrupted knots in the 3-, 6-, 9-, and 12-o'clock positions. A running mattress suture was used to secure the pericardium to the leaflet and create a leak-free seal.

Statistical Analysis

All hemodynamic and chordal force data were ensemble averaged for 10 cardiac cycles. MR was quantified by integrating the negative (or reverse) flow over the systolic portion of the cardiac cycle. The presence of MR was confirmed by Doppler echocardiography. Philips Qlab (Phillips Healthcare, Andover, Mass) was used to quantify the MV leaflet coaptation length measured at the A2-P2 coaptation line. Chordal force data are presented as the difference between the peak systolic and peak diastolic force. The percentage of improvement in coaptation length (increase in coaptation length) and chordal force (reduction in force) was calculated between the postoperative repair and FIMR groups.

The measured endpoints were checked for normality using the Anderson-Darling test. The independent samples *t* test and 2-way analysis of variance were used when appropriate. A Tukey post hoc test was used to further investigate significance. All statistical analyses were completed using Minitab, version 16 (Minitab, Inc, State College, Pa). All data are reported as the mean ± standard deviation.

RESULTS

Functional Ischemic MR

FIMR was successfully simulated with asymmetric annular dilatation and PM displacement for all experiments (3+ MR grade, n = 4; 4+ MR grade, n = 11). Large, asymmetric regurgitant jets were observed using color Doppler echocardiography. Leaflet tethering was observed, and the coaptation length was significantly decreased from that of the control group (control group, 4.8 ± 0.5 mm; FIMR group, 3.2 ± 0.5 mm; $P < .005$) at the central A2-P2 plane (Table 1).