Author has nothing to disclose with regard to commercial support.

resection, or preservation of the prolapsing segment of the posterior mitral leaflet have been shown to be effective and should remain as useful tools in the surgeons' surgical armamentarium, because each may have special applicability to different types of valve pathology. Namely, when there is "excessive" leaflet tissue, appropriate resection may be indicated. Their position is very well illustrated by the flowchart that constitutes their central picture.

The letter of Tomšič and colleagues¹ reinforces the idea that I had expressed in the Editorial Commentary that accompanied the original article of Mazine and colleagues,² "Isolated Posterior Mitral Leaflet Prolapse: Resect, Respect, or Resect With Respect?"³ There are questions remaining: How excessive is excessive? And how extensive should the resection be? The whole or part of the prolapsed segment?

This is precisely what I meant by "resect with respect." Actually, Mazine and colleagues² were already pointing in the same direction when they stated that "it is critical that mitral surgeons can utilize several different techniques individualized to the quality and quantity of mitral tissue, as well as each patient's specific dysfunction and lesions."

In fact, though, the main message of the article by Mazine and colleagues² was that preservation of the leaflet might achieve better functional results, not only in terms of preserving an adequate valve orifice, thus potentially avoiding mitral stenosis, a "complication" previously described in the literature, but also in terms of preservation of left ventricular function, by avoiding distortion of the mitral valve apparatus. In the meta-analysis performed by Mazine and colleagues,² reoperation was more frequent in the resection group, although no difference in recurrence of mitral regurgitation was detected. As Tomšič and colleagues¹ underlined, however, "most reoperations were performed shortly after the initial operation, indicating technical failure. Indeed, ring dehiscence was the most common cause of reoperation." Tomšič and colleagues¹ also considered that "the type (and size) of annuloplasty device can potentially cause unwanted, clinically significant functional mitral valve stenosis."

These two problems will probably remain a matter of discussion in the foreseeable future. Personally, I have never come across a single case of significant postrepair mitral stenosis, and it is unlikely that it will occur except after excessive reduction of leaflet tissue or use of extremely small rings. On the other hand, I cannot understand how can one of these techniques achieves better preservation of left ventricular function, because neither alters the

ventricular geometry significantly. Perhaps the ongoing Canadian Randomized Trial will shed some light on this puzzle.

Finally, I wish to comment on an aspect that I failed to highlight in my Editorial Commentary. In their article, Mazine and colleagues² stated that theirs was "the first systematic review and meta-analysis to compare leaflet resection versus chordal replacement techniques for the repair of isolated posterior mitral leaflet prolapse." It is always dangerous to make such statements. Simultaneously, Mihos and colleagues⁴ published, in another journal, "A Systematic Review and Meta-analysis of Chordal Replacement Versus Leaflet Resection for Isolated Posterior Mitral Valve Prolapse" (please note the extreme similarity of the title!).

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EULER'S ELASTICA-BASED BIOMECHANICAL ASSESSMENT FOR NEOCHORDAL INSERTION IN THE TREATMENT OF DEGENERATIVE MITRAL VALVE REPAIR

To the Editor:

We read with interest the commentary of Padala¹ in response to the article from Yoshida and colleagues² in the *Journal*. Despite fully supporting Padala's detailed and thorough analysis,¹ we believe that a comprehensive understanding of degenerative mitral repair requires the evaluation not only of the morphologic aspects but also of the baseline biomechanical characteristics of the mitral valve tissues involved (leaflets, chordae tendineae, papillary muscles) and the physical stresses acting on these structures.

Yoshida and colleagues² elegantly presented the use of 320-slice computed 2- and 3-dimensional tomography for

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the preoperative assessment of the length of chordae tendineae, with the aim of acquiring a precise value of the distance between the papillary muscle tip and leaflets to tailor valve repair with the implantation of neochordae accurately.

An important limitation of this approach is that the measurements are achieved in a static state. The application of a finite element analysis, which is amenable to the study of dynamic processes, may provide a more comprehensive understanding of the mitral configuration. Finite element analysis is a powerful tool to analyze complex geometric systems in quasistatic and dynamic conditions, as systolic-diastolic changes occur throughout the cardiac cycle.³

The possibility of building finite element analysis from 3-dimensional real-time echocardiography and combining these analyses with biomechanical modeling might further enhance the power of this methodology, including data on preoperative systolic mitral leaflet stresses, tensile forces applied to primary and secondary chordae tendineae, and force inclination. Indeed, if applied to the entirety of the mitral valve apparatus, (ie, papillary muscles, primary and secondary chordae tendineae, and leaflet), it may allow

the calculation of differential grades of stress on the valve components to predict potential modes and sites of repair failure and provide guidance for the optimal number of chordae to be used.⁴

In addition to the linear length, another important parameter not to be neglected in the assessment for neochordal insertion is the elastomechanical property of the native and prosthetic chordae, which significantly affect the geometry and dynamic function of the mitral valve complex. In our group, we have developed a mathematical model that applies the principle of Euler's elastica to the mitral components.⁵ Chordae tendineae encounter uniaxial tensile loading in physiologic conditions and can be modeled as 1-dimensional (incompressible) elements obeying the Fung nonlinear elastic behavior. The mitral valve leaflets are modeled as nonlinear parallel cantilever beams subjected to end-point loads in systole, the magnitudes and slopes of which are associated with the directions and intensities of the axial tensile forces in the chorda tendineae to ensure deformation compatibility and equilibrium. An inextensible elastica with length l clamped on a side and loaded by an arbitrary oriented force P on the other extremity is thus considered, under the well-known Bernoulli constitutive assumptions (Figure 1). The neochordae exert the action in a quasistatic state (diastole) and under dynamic stress (systole), with the boundary condition obtained by following the Bisshop method. The shape of each valve

FIGURE 1. Three-dimensional echocardiographic reconstruction exemplifying the relationship between the papillary muscles and leaflets (left) is shown with reference to a sketch of the in-plane mechanical modeling of the mitral valve nonlinear bending and tethering due to the interaction with hyperelastic chordae anchored to a moving papillary muscle site (right). Equations and assumptions at the basis of this model are as follows: [1] $\theta'(s) = \frac{M(s)}{B}$, $s \in [0, l]$, in which B represents bending stiffness, which establishes a linear relationship between the bending movement M and the curvature θ' ; that is, the derivative of the angle θ representing the slope of the tangent to the elastica at each curvilinear abscissa, s . Bisshop method: [2] $\Theta(s) = \arcsin[2K^2 \sin^2 \varphi(s) - 1]$. Cauchy stress: [3] $\sigma = \frac{\partial \psi_c}{\partial e} = C_1(e^{c_2 e} - 1) = T\lambda$, where $T = P/A_{ref}$ denotes the Piola-Kirchhoff nominal stress; that is, the edge load per unit reference cross-sectional area of the tendon. A, Anterior; AL, anterior leaflet; PM, posterior mitral leaflet; P (left figure), posterior; alpha, leaflet angle; l_c , chordae tendineae length clamped on a side; P (right figure), oriented force or load; $\theta(s)$, curvature or slope of the tangent to the elastica at each curvilinear abscissa, s (see equation [1]); $x(s)$ $y(s)$, reference for position in space; u , interpapillary distance.

leaflet where the neochordae are inserted can be described by means of 2 Lagrangian parameters governing the deformation of the beam, which are the end-point angle θ_l and the force inclination α (Figure 1). As a matter of fact, the angle α is determined by the orientation of the chorda tendinea and depends on both the angle θ_l and the position of the papillary muscle. Other factors that require considerations are material constants, which can be modeled by the tensile Cauchy stress σ and by Piola-Kirchhoff nominal stress and represent the edge load per unit reference cross-sectional area of the neochordae. Material constants are important, because the insertion of neochordae occur on degenerated leaflets and tissues that are composed of a different mechanical resistance than a normal leaflet.

In conclusion, we congratulate Yoshida and colleagues² and Padala¹ for their work. We believe that a model taking into account not only geometric but also biomechanical and functional dynamic parameters is of paramount importance to our exhaustive understanding of the issues relative to degenerative mitral disease.

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IS INDIVIDUALIZED MITRAL VALVE REPAIR IN THE FUTURE?

Reply to the Editor:

We appreciated the editorial commentary¹ by Dr Padala on our study² and enjoyed reading the letter to the Editor, “Euler’s Elastica-Based Biomechanical Assessment for Neochordal Insertion in the Treatment of Degenerative Mitral Valve Repair” by Nappi and colleagues.³

We agree with Padala¹ and Nappi and colleagues³ that both the morphologic and biomechanical characteristics of the mitral leaflets are important in the treatment of mitral regurgitation (MR).^{1,3} Although the biomechanics of the subvalvular apparatus have been discussed in the *Journal* as a pivotal mechanism in ischemic MR,³ we focused on the detailed morphologic evaluation of the leaflets and subvalvular apparatus in patients with degenerative MR to achieve precise and individualized mitral repair.² When performing a morphologic evaluation, electrocardiogram (ECG)-gated computed tomography (CT) exquisitely displays dynamic cardiac anatomy at any phase. Subsequent to the introduction of transcatheter aortic valve implantation, preoperative evaluation of the aortic annulus, sinus of Valsalva, and coronary artery orifices has been performed using ECG-gated CT. We used this technology for evaluation of the valvular and subvalvular geometry of the mitral valve. In contrast to evaluation of the aortic root, evaluation of the mitral leaflets is difficult because

FIGURE 1. Mitral valve configuration after repair surgery using reconstruction with artificial chordae precisely measured using 320-slice CT in a patient with normal mitral leaflets and torn chordae (left) and a patient with more elastic or redundant leaflets (right).