Authors have nothing to disclose with regard to commercial support.

they are thinner and move rapidly. However, evaluation of the mitral leaflets is possible in the midsystolic phase when there is minimum movement. In addition, evaluation of the papillary muscles using ECG-gated CT is more useful than echocardiographic evaluation because the number and size of the papillary muscles remain obscure on an echocardiogram.⁴

Although our study demonstrated precise and dynamic morphologies of the mitral leaflets and subvalvular apparatus, assessment of biomechanical characteristics of the mitral valve may become more important for understanding mitral valve disease and developing new surgical treatments. In particular, elucidation of differences in elastic behavior between degenerated and normal leaflets may become an important target of mitral valve repair. More elastic mitral leaflets in extensive degenerative regions may require intraoperative adjustment to correct the length of artificial chordae,⁵ even though the distance between the tips of the papillary muscles and the normal leaflets is precisely measured with our technique using 320-slice CT because of redundancy and the different elasticity of mitral valve tissue in degenerative regions (Figure 1). This redundancy and different elasticity may cause difficulty in accurate length assessment of artificial chordae.

We expect that the biomechanical assessment proposed by Nappi and colleagues³ will allow us to achieve more precise and individualized estimation of the length of artificial chordae in degenerative tissue with different elasticity.

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<https://doi.org/10.1016/j.jtcvs.2017.09.114>

PATIENT-SPECIFIC COMPUTATIONAL BIOMECHANICAL MODELING TO GUIDE MITRAL VALVE REPAIR STRATEGY: PRACTICALITY AND VALUE?

Reply to the Editor:

Finite element modeling (FEM) emerged in the 1950s from the work conducted by Jonathan Turner at Boeing Corporation. He developed the direct stiffness method and the first continuum-based finite elements for application to nonlinear problems. These seminal contributions were refined and later applied toward investigating structural mechanics in the aerospace industry, civil engineering, and machinery to reduce the burden of expensive experiments and decrease the design cycle time. Today, FEM modeling has become the standard in designing structures and optimizing material selection to ensure a robust design. In the past 2 decades, improvements in computational power and biomedical imaging have led to the application of FEM modeling to study the stresses on load-bearing structures in the human body (ie, heart valves, myocardium, blood vessels, knees, lungs) to correlate with the underlying biology. Mechanobiology, that is, the link between mechanics and biology, is now a thriving field with applications not only in cardiovascular disease but also in cancer therapeutics.

Nappi and colleagues¹ present a reasonable argument that FEM modeling can be applied in a patient-specific manner for planning heart valve repairs, in this case mitral valve repair for degenerative valve disease. Availability of 3-dimensional echocardiography data, with excellent spatial resolution and adequate temporal resolution, enables segmentation of the dynamic valve structure throughout the cardiac cycle and computation of temporal changes in the tissue stresses. The virtual nature of this platform also allows evaluation of a variety of surgical techniques on the dynamic valve model before implementing in the patient. The ability to iterate and optimize a surgery in this manner is appealing and could theoretically help in refining the repair for better biomechanics and ultimately better outcomes. In this specific communication, Nappi and colleagues¹ report a biomechanical model for the mitral valve, considering the chordae tendineae as 1-dimensional elements with Fung nonlinear elastic behavior and the leaflets as nonlinear parallel cantilever beams with end-point

Author has nothing to disclose with regard to commercial support.

loads in systole. This simple model is used to assess the optimal length and site of neochordae insertion, and their impact on the cantilever-like beam representing the leaflet. The model is simple and elegant, but limited in representing the native valve geometry, its heterogeneity from rough to smooth zone, the chordal distribution, and the material characteristics, and thus is possibly rudimentary.

Application of biomechanical modeling in a patient-specific manner to mitral valve repair warrants some introspection and consideration for its practical application in the clinical workflow. First, all biomechanical models of the mitral valve are overtly simplified by using representative valve geometries, averaged material properties, and limited dynamism in the surrounding structures, all of which render the model nonpatient specific. Although attempts to improve mitral valve imaging are under way, the standard of care imaging (3-dimensional echocardiography or magnetic resonance imaging) cannot capture the chordae tendineae connecting the leaflets to the papillary muscles. High-resolution, multislice, dyna-computed tomography can provide this information, but would be impractical to use in these patients who otherwise would not require exposure to radiation. Second, all biomechanical models use averaged mechanical properties of healthy and diseased valves from the literature, which limits their application toward optimizing specific patients repair. Specifically, in degenerative mitral valve disease, in which the pathologic mechanism underlying leaflet degeneration and prolapse could vary between patients, the use of averaged mechanical properties could be misleading. Attempts to use an inverse modeling approach using valve deformation to iteratively compute the best-fit material constants are ongoing, but it is an exercise that is more top-down and not representative of the valve pathology to predict future durability. Third, whether stress distributions from such computational models translate into tangible and practical intraoperative decisions is questionable. A 1- to 2-mm shift in the neochordae location or length could significantly

change the leaflet motion and stress distribution in the mitral valve computational model, but it remains to be seen whether such small changes can be implemented by a surgeon working in a limited field of view, encountering leaflet clefts that reveal themselves during intraoperative surgery and focused on keeping the crossclamp and cardiopulmonary bypass times as minimal as possible.

The anatomic measurements proposed² for intraoperative repair are not ideal either, yet provide a practical step for a surgeon without concentrated experience in mitral valve repair to choose neochordoplasty over replacement. The proposed model is based on historical data³ that marginal chordae are twice as stiff than the basal chordae and deform less than the basal chordae in systole. Thus, a hypothesis that the marginal chordae act as anchors that align the leaflet edge and the more extensible basal chordae elongate and provide the curvature required to form the leaflet shelf seems reasonable to us. By measuring the marginal chordal lengths against the basal chordae, leaflet edge parallelization in systole may be restored for a sufficient leaflet coaptation height.

With increasing computing power and tools to generate high volumes of data, we are all increasingly developing a thirst for big data and drawn away from developing a better understanding of the available data. Careful intraoperative valve examination, simple anatomic measurements in relation to the intact mitral valve, and some thought might help make mitral valve repair easier and more effective.

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