The Mitral Valve Complex: Divine Perfection

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The characteristic term mitral valve for the left atrioventricular valve was first suggested by Andreas Vesalius because of its resemblance to a bishop’s miter. The mitral valve has 2 leaflets with different shapes and circumferential lengths, and these leaflets act together to prevent back flow to the left atrium during the ventricular systole. The anterior leaflet, which is in fibrous continuity with the aortic valve, occupies one third of the annular circumference with a rounded free edge. The posterior leaflet is long, narrow, and composed of 3 distinct scallops—medial, middle, and lateral—that line the remainder of the circumference of the annulus. The mitral valve coapts effectively when all the related components surrounding the leaflet act properly. The mitral valve complex, which is composed by (1) annulus, (2) leaflets, (3) chordae tendineae, (4) papillary muscles, and (5) left ventricular wall, is miraculously balanced both geometrically and functionally.

To be a principal mechanism of secondary MR, mainly from experimental animal studies, in the beginning of the 21st century, transthoracic real-time 3D echocardiography became commercially available, followed by transesophageal real-time 3D echocardiography. Real-time 3D echocardiography allows one to noninvasively obtain whole-heart images at the bedside, and some dedicated software has made it possible to reconstruct realistic images of the mitral valve apparatus and quantify the degree of geometric changes of the mitral valve complex. Our group has reported the 3D assessment of the mitral valve remodeling in ischemic/functional MR by using transthoracic and transesophageal echocardiography. The saddle-shaped mitral annulus is flattened with leaflet tenting toward the left ventricular in patients with secondary MR, and the degree of mitral complex deformity can now be quantified in each individual. These quantitative 3D images have contributed to further understanding of the 3D morphological characteristics of the valve components with papillary muscle alignment, which plays an important role in functional MR secondary to left ventricular dysfunction. At the same time, transesophageal 3D echocardiography is able to provide relatively high-resolution images of the mitral valve apparatus and has made it possible to observe the enface view of the valve leaflets before surgery. The feasibility and clinical usefulness of 3D observations of the mitral valve have been reported, and this relatively new technology is already widely used as a guide for valve repair surgery.

Computer-generated simulations of the mitral valve have been conducted to investigate the mechanical influence of valve apparatus deformation. Salgo et al proved that the saddle-shaped annulus confers a mechanical advantage to the leaflets by adding curvature. A recent report by Kim et al introduced virtual mitral valve apparatus models created by 3D transesophageal echocardiographic data of patients with normal and pathological mitral valves, and valve function was evaluated by computational simulations.

In this issue of Circulation: Cardiovascular Imaging, Ben Zekry et al attempt to quantitate patient-specific global strain of the mitral valve apparatus and its regional dynamic deformations with the use of a novel computerized tracking system for volumetric images by 3D transesophageal echocardiography in a normal patient population and then compare the results with those measured in patients with organic MR. What is new in their tracking system compared with previous computerized simulation systems is that the strain analysis of leaflet deformation in this study is based on valve anatomy without any computer assumption on tissue elasticity.

This study is a pilot study that tests the previously published computer analysis system for the quantitative measurements of mitral valve strain in small patient groups. Volumetric images of the mitral valve apparatus were obtained by full-volume acquisition with the use of 3D transesophageal echocardiography.

See Article by Ben Zekry et al
The study population included 10 patients with a normal heart and mitral valve and 10 patients with moderate-to-severe MR caused by flail leaflets. Mitral valve dynamic tracking was performed after manual tagging of the mitral annulus and leaflets using Slicer 3D software. Patient-specific static models of the mitral annulus and leaflets were created with bicubic spline fitting technique based on MATLAB procedures. The reconstructed annulus and leaflet were then tracked between mid-systole and end-systole to investigate patient-specific mitral apparatus deformation. Leaflet geometric strain was computed based on the algorithmically assumed deformation around each point of the point meshes. The authors defined 8 geometric regions of interest for each leaflet, referring to the reconstructed patient’s leaflet model at mid-systole. The anterior leaflet and 3 posterior scallops were generated semiautomatically after manual tagging to separate each leaflet. High-strain zone/area(s) were then computed and mapped.

According to their results, leaflet strain intensity was higher in posterior leaflets than the anterior leaflet both in the normal group and the organic MR group. Comparing the 2 groups, mean strain intensity was greater in the flail leaflet group than the normal group. The regional analysis of leaflet strain showed that leaflet strain concentrations were the highest in the commissure zone and the lowest in the center zone.

On the basis of their data, the authors suggest that (1) quantitative measurements of strain distributions using computed patient-specific mitral valve models are feasible in human subjects and (2) patients with organic MR caused by flail leaflet have higher leaflet strain than normal subjects.

The contributions of this study to our knowledge of the mitral valve complex geometry and function are important. First, this is the first trial that measures mitral valve deformation and tissue stress in vivo humans by analyzing patient-specific mitral valve models reconstructed from the clinically recorded 3D echocardiographic images without computed simulation. Although the leaflet stretch phenomenon and larger distensibility in the posterior leaflet than anterior leaflet have been reported by in vitro study using an animal model,\(^1\) valve strain along with cardiac motion in human subjects have not been previously shown.

Although leaflet tissue strain during the cardiac cycle should play an important role in proper mitral valve coaptation, previous investigations on mitral valve complex geometry and function have largely ignored the ability of the leaflet to stretch because of the lack of measurement technique in the clinical setting. Chaput et al\(^{20}\) have reported on mitral valve adaptation in patients with chronic left ventricular dysfunction. They found that the mitral valve was enlarged with histological remodeling and suggested that valve adaptation contributes to reduce the degree of functional MR. This study reinforces the regional valve stretch phenomenon in the normal mitral valve. The mitral valve apparatus, consisting of the saddle-shaped annulus and curved leaflets with variable regional distensibility, coupled with papillary muscle alignment seems to be perfectly designed to coapt effectively throughout the cardiac cycle. In addition, global and regional leaflet strains were significantly larger in patients with organic MR caused by flail leaflet compared with patients with normal mitral valves. Further investigations, including various types of valve conditions, such as billowing type prolapse or Barlow’s syndrome, should give us new insights into the pathophysiology of leaflet function.

Third, leaflet strain mapping, although still evolving, has demonstrated heterogeneity of the valve strain concentrations that are the greatest in the commissure region and the lowest in the center region. The beautiful images of the strain mapping of the mitral valve derived from 3D echocardiographic data from the beating human heart will facilitate the echocardiographic assessment of mitral valve tissue pathology. Furthermore, valve strain should be greatly influenced by the hemodynamic condition of each individual. Blood pressure should be one of the important factors that can affect the strain concentration and strain measurement throughout the cardiac cycle and would be an important consideration for the study. Future clinical research should investigate the feasibility and accuracy of this novel imaging technology with a large patient population with various conditions. Further investigation is needed to validate the computed strain data using this novel computer-generated 3D analysis system.

Disclosures

None.

References


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