Perspective

4D-transesophageal echocardiography and emerging imaging modalities for guiding mitral valve repair

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Submitted Dec 31, 2014. Accepted for publication Jan 17, 2015.
doi: 10.3978/j.issn.2225-319X.2015.02.01
View this article at: http://dx.doi.org/10.3978/j.issn.2225-319X.2015.02.01

Two-dimensional transesophageal echocardiography (2D-TEE) had a transformative impact on surgical treatment of mitral valve pathology in the 1980s. 2D-TEE provided unprecedented, high-quality views of the mitral valve that enabled pre-operative repair strategizing and immediate post-operative assessment of repair efficacy. Several decades later, the commercialization of four-dimensional transesophageal echocardiography (4D-TEE) and other emerging imaging modalities such as 4D computed tomography (4DCT) and cardiac magnetic resonance imaging (CMRI) potentiate yet another transformative phase in the practice of mitral valve repair surgery. Bypassing the "mental integration" step required for 2D image interpretation, these higher dimensional modalities provide a more intuitive, complete description of valve morphology and dynamics that can be leveraged as a tool for more effective surgical decision support. Current research shows that these modalities may enhance mitral valve repair outcomes in four ways: (I) by increasing the precision of mitral valve diagnostics in order to tailor the repair plan to an individual's valve pathology; (II) as a means of risk stratification to determine which patients might benefit from valve repair over valve replacement; (III) by predicting the outcome of a given repair technique using image-derived valve models as input to computational biomechanical analysis; and (IV) by optimizing annuloplasty ring design. Research highlights in each of these areas are given below.

Increasing diagnostic precision

Chandra and colleagues (1) have demonstrated that quantifiable morphological features derived from 4D-TEE analysis can effectively classify the etiology of degenerative mitral valve disease. Differentiation of patients with Barlow's disease and fibroelastic deficiency, which is often not straightforward, influences the anticipated complexity of repair—knowledge of which can facilitate an appropriate match between the patient's valve pathology and the skill set of the surgeon performing the repair. Optimizing this match may prevent patients with repairable valves (in the hands of a surgeon with subspecialty expertise) from undergoing unnecessary valve replacement (in the hands of a surgeon with a greater comfort level with this less preferred, yet simpler, operation).

Risk stratification

Levack *et al*. (2) have identified 4D-TEE derived mitral leaflet tethering indices that are predictive of repair failure in patients with ischemic mitral regurgitation, a disease associated with the highest rates of early (<6 months) moderate to severe disease recurrence. Image-based pre-operative repair risk assessment can help identify patients who are better suited for valve replacement than valve repair and thereby decrease the number of operations these patients undergo to successfully treat mitral regurgitation.

Predicting repair outcome

Several research groups have demonstrated that three-dimensional image-derived models of the mitral valve can be used as patient-specific, anatomically accurate input to computational biomechanical simulations. Such analyses can predict post-repair valve geometry or estimate stress distributions on the mitral leaflets. For example, Mansi *et al*. (3) present an integrated framework for estimating personalized geometrical mitral valve models from 4D-TEE images and using these models as input to finite element analysis to simulate valve closure. The predictive power of the model is evaluated on a patient who underwent MitralClip repair by comparing the simulated intervention with the real outcome in terms of mitral valve closure. Such tools may be used in the future for operation planning and performing virtual surgeries.

Annuloplasty optimization

Zhang *et al*. (4) have described that 4D flow information obtained with phase contrast CMRI can be used to assess the effect of various annuloplasty ring geometries on left ventricular hemodynamics. Understanding how annuloplasty designs impact left ventricular blood flow may have the greatest implications in patients that are surgically treated for ischemic mitral regurgitation because of the impaired left ventricular function associated with this disease.

Discussion

A requirement of the applications described above is the need for advanced automated methods for extracting or delineating valve geometry and motion in 4D images. Whilst this was previously a labor-intensive undertaking, obtaining detailed patient-specific models of the mitral valve from these images is becoming an automated process rather than a manual task [Mansi *et al*. (3), Pouch *et al*. (5), Schneider *et al*. (6)]. Automation will help minimize the time required for experts to interpret high dimensional image data, reduce inter-observer variability in valve delineation, and enable the processing of large quantities of image data to support research in improving mitral valve repair. Moreover, as mitral valve surgery becomes less invasive with the development of percutaneous approaches, 4D-TEE image acquisition and analysis will play an ever more important role in surgical guidance.

Acknowledgements

None.

Footnote

Conflicts of Interest: The authors have no conflict of interest to declare.

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Cite this article as: Pouch AM, Jackson BM, Yushkevich PA, Gorman JH 3rd, Gorman RC. 4D-transesophageal echocardiography and emerging imaging modalities for guiding mitral valve repair. Ann Cardiothorac Surg 2015;4(5):461-462. doi: 10.3978/j.issn.2225-319X.2015.02.01

