Three-Dimensional Echocardiography of the Mitral Valve

Stanton K. Shernan, MD, FAHA, FASE
Professor of Anaesthesia
Director of Cardiac Anesthesia
Department of Anesthesiology, Perioperative and Pain Medicine
Brigham and Women’s Hospital
Harvard Medical School

Over the past 30 years, technological advances have significantly contributed to the development of perioperative echocardiography in becoming an invaluable diagnostic tool and monitor of cardiac performance for the management of cardiac surgical patients. Intraoperative echocardiography was first introduced into clinical practice in the early 1970’s for the evaluation of open mitral valve (MV) commissurotomy, using M-mode ultrasound via an epicardial approach with conventional transthoracic echocardiographic probes enclosed in sterile sheaths. The introduction of intraoperative transesophageal echocardiography (TEE) in the early 1980’s provided the catalyst for subsequent innovative developments. Consequently, modern day echocardiography probes and consoles that are currently capable of producing high resolution, multiplane two-dimensional (2D) images of cardiovascular anatomy and permitting accurate, noninvasive quantification of blood flow have made significant contributions to perioperative clinical decision-making and outcomes.

Although the concept of three-dimensional (3D) echocardiography was first introduced in the early 1970s, its utility in the perioperative environment has only recently acquired appropriate recognition. Advantages of both conventional 3D reconstruction and real-time 3D imaging techniques for enhancing the diagnostic confidence of conventional echocardiography in the perioperative period have begun to emerge in the literature. Primary areas of interest have included the utility of 3D echocardiography in preoperative surgical planning, intraoperative assessment of the surgical procedure, and postoperative early and long-term follow up to determine the need for further intervention.
Perioperative 3D echocardiography may offer some primary advantages over 2D echocardiography for patients undergoing MV surgery. Preoperative 3D echocardiography has been very useful in delineating mechanisms of MV disease to potentially facilitate surgical planning. Three-dimensional echocardiography has been particularly valuable in delineating changes in the MV apparatus associated with ischemic mitral regurgitation (MR) including globular flattening, dilatation and heterogeneous regional remodeling of the annulus (1,2); increases in tenting volume and a shift in maximal tenting area towards the anterior commissure (3); geometric differences between anterior myocardial infarction (MI) versus inferior MI (4,5), and geometric differences between ischemic and dilated cardiomyopathy respectively (6). The contributions of 3D echocardiography to our understanding of pathophysiological mechanisms responsible for ischemic MR may have important implications regarding surgical approaches to repairing the MV apparatus. Furthermore, several studies have demonstrated superior accuracy of preoperative 3D compared to 2-D echocardiography in diagnosing MV anatomic pathology related to mechanisms and etiologies other than ischemic MR, as well as delineating MR jets in patients scheduled for MV repair.

In addition to the potential utility of 3D echocardiography for facilitating surgical planning in the preoperative period, 3D intraoperative echocardiography can also provide a potentially more efficient process for acquiring a comprehensive echocardiographic examination of the MV, which may be particularly important in the volatile intraoperative environment where timely and effective clinically relevant decision-making may be critical. By enabling the inclusion of depth and volume, and the ability to rotate and crop whole volume data sets without any directional restriction, more data is available for interpretation in a given imaging window. Thus, 3D echocardiography may be superior to 2D techniques for more efficiently defining important geometric relationships between components of complex intracardiac structures such as the mitral apparatus (7,8).

In addition to enabling potentially greater efficiency in performing a comprehensive intraoperative TEE examination, 3D TEE may also permit more accurate diagnoses and more effective communication with interventionalists (9,10). Unique imaging windows of the MV which are not readily obtainable with 2D, can be presented in en-face perspectives to better appreciate anatomy and functional geometry, and help
communicate relevant diagnostic information to those less familiar with echocardiographic displays. These unique views may be more familiar to cardiac surgeons and cardiology interventionalists, and may therefore facilitate a better understanding of abnormal anatomy and associated pathology. Abraham et al performed intraoperative 2-D and 3-D reconstruction TEE examinations on 60 patients undergoing valve surgery (11). In this study, 3-D acquisitions were completed in 87% of the patients within a mean acquisition time of 2.8 ± 0.2 minutes and reconstruction time within 8.6 ± 0.7 minutes. Three-D echocardiography detected all salient valve morphological pathology (leaflet perforations, fenestrations and masses) which was subsequently confirmed on pathological examination in 84% of the patients. In addition, intraoperative 3-D TEE provided new additional information not obtained by 2-D TEE in 15 patients (25%), and in 1 case influenced the surgeon’s decision to perform a valve repair rather than a replacement. Furthermore, intraoperative 3-D reconstruction TEE provided worthwhile and complimentary anatomic information that explained the mechanism of valve dysfunction demonstrated by 2-D imaging and color flow Doppler. Ahmed et al evaluated the potential utility of 3-D TEE in identifying individual MV scallop prolapse in 36 adult patients with undergoing surgical correction (12). Perfect correlation between 3-D TEE and surgical findings was noted in 78% of the patients. Similarly, De Castro et al demonstrated superior concordance between intraoperative 3-D TEE surgical identification of prolapsing anterior and posterior MV scallops compared to 2-D TEE (13). Intraoperative 3-D TEE has also been used to identify distortion and folding of the mitral annulus as a cause of functional mitral stenosis or worsening mitral regurgitation during beating heart surgery while positioning to access the back of the heart (14).

In addition, the ability to use 3D TEE to diagnose complex congenital heart lesions and valve abnormalities including MV clefts and commissural lesions which often co-exist with more commonly encountered pathology (i.e., flail posterior leaflets), may enable more effective surgical planning since some of these findings are often subtle and difficult to appreciate in the unloaded heart during cardiopulmonary bypass (10,15,16). Furthermore, accurately identifying the specific location and severity of MR jets especially immediately following valve repair or replacement can also facilitate decision-making regarding
the need for urgent further intervention (17). Finally, 3D echocardiography can also assist in determining mechanisms and severity of dynamic pathophysiological states which often require surgical intervention including functional MR, hypertrophic obstructive cardiomyopathy and systolic anterior motion of the MV (18).

There is considerable enthusiasm pertaining to the current utility of 3D TEE technology and its potential favorable impact on perioperative decision-making, however certain current limitations are worth noting. For example, while 3D reconstruction software and hardware using standard 2D, phased array multiplane probes has been commercially available for over 10 years, this technology still relies on stable cardiac rhythms, respiratory and ECG gating, and both time and expertise for full volume acquisition reconstruction and “editing”, which together may impose practical challenges in the operating room environment when attempting to efficiently obtain quality images worthy of interpretation. Three-dimensional TEE using miniaturized matrix arrays has been introduced more recently, and permits the acquisition of true “real-time” full volumes (19-22). However, some spatial and temporal resolution limitations, and the current need for hybrid reconstruction to incorporate full volume 3D color flow Doppler images, should be considered when comparing this advanced technology to “time-tested” 2D echocardiographic platforms. In addition, both reconstruction and real-time 3D TEE techniques still require a reasonable time commitment to learn how to acquire, manipulate, qualitatively interpret and quantitatively analyze full volume echocardiographic images and data sets.

Nonetheless, intraoperative 3D echocardiography is likely here to stay. Assuming continued exponential growth in the technological development of more sophisticated ultrasound transducers, the introduction of improvements in image acquisition, processing speed, real-time volume rendering with superimposed color flow doppler and transducer miniaturization, it is likely that future developments in 3D echocardiography may even permit the construction of individualized prosthetics and the creation of virtual surgical platforms. While the direct impact of 3D TEE on surgical outcomes has yet to be determined, perioperative 3D echocardiography will undoubtedly continue to improve upon the efficiency, accuracy and
communication of important diagnoses related to cardiovascular disease thereby facilitating clinical decision-making.

REFERENCES

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