

iFORUM

NEWS AND VIEWS

Three-Dimensional Echocardiography: Is it Ready for Everyday Clinical Use?

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SINCE THE EARLY DAYS OF B-MODE ECHOCARDIOGRAPHY, the instrumentation and applications of echocardiography have expanded rapidly. In the early 1990s, von Ramm and colleagues developed the first prototypes of real-time 3-dimensional echocardiography (RT-3DE). In 2009, RT-3DE is available in many laboratories on newer ultrasound machines.

It has shown its mettle in the accurate measurement of left ventricular mass, volumes, and ejection fraction. It has been used successfully in the careful assessment of valvular heart disease. An ideal application is in mitral valve disease, especially in operating room scenarios before mitral valve repair, to aid the cardiac surgeon in surgical planning. Congenital heart disease is another obvious useful application of 3D echocardiography. New horizons include its use in stress testing and perfusion imaging with echocardiographic contrast. Drs. Lang and Mor-Avi do a wonderful job of pointing out its strengths in this edition of *iForum* in *iJACC*.

The real question for 3D echocardiography is: how is it to fit into the clinical routine? There are issues with training and workflow and limitations in terms of image storage and transmission. How do echocardiographers interpret these data, e.g., do they refer back to the 2-dimensional (2D) model in their mind's eye? How do echocardiographers make use of this wealth of data in a timely fashion that is practical for referring clinicians? Is it cost-effective? These and other important questions are raised by Dr. John Dent in his excellent review of the potential drawbacks and solutions for 3D echocardiography

in the accompanying piece for *iForum*. We hope you enjoy this open discussion and feel free to e-mail or send more formal correspondence to *iJACC* in response.

The Time to Adopt RT-3DE in the Clinical Routine Is Now!

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OVER THE LAST 3 DECADES, 3D ECHOCARDIOGRAPHIC IMAGING HAS BEEN DEVELOPED with the aim of providing additional anatomic detail and improved spatial relationships that were not available from 2D images. To achieve this goal, the most significant advance during the last decade was the introduction of matrix-array transducers, which have enabled the transition from slow and labor-intensive off-line reconstruction of 3D datasets to real-time volumetric imaging. These transducers, which contain arrays of piezoelectric elements capable of scanning pyramidal volumes rather than thin slices, allow fast acquisition of RT-3DE datasets during a single breath-hold, without the need for off-line reconstruction. This, to a large extent,

has eliminated motion artifacts known to have adversely affected the now-outdated multiplane acquisition and reconstruction. The use of parallel processing met the need for increased computational power, which was necessary to process the information generated by these matrix-array transducers.

The potential benefits of RT-3DE imaging have been described in several areas (1), including: 1) direct measurements of cardiac chamber volumes; 2) direct 3D assessment of regional left ventricular (LV) wall motion at rest and during stress testing, with and without contrast, as well as quantification of systolic dyssynchrony to guide ventricular resynchronization therapy; 3) realistic “surgeon’s views” of the mitral valve; 4) 3D color Doppler imaging with volumetric quantification of regurgitant lesions, shunts, and cardiac output; and 5) 3D imaging and volumetric quantification of myocardial perfusion.

The main reasons for requesting an echocardiogram in routine clinical practice is to assess global and regional left ventricular function. To date, this assessment is mostly performed using “eye-balling” of dynamic ultrasound image sequences, which requires training and experience. The limitations of this subjective interpretation have been long recognized, and consequently, the use of quantitative techniques has been recommended. The relative inaccuracy of the 1D and 2D echocardiographic approaches has been attributed to the need for geometric modeling of the ventricle and the common use of “foreshortened” views of the ventricle. In this regard, the biggest advantage of 3D echocardiography is the lack of dependence on geometric modeling and image plane positioning, resulting in more accurate chamber quantification. Not surprisingly, most studies that have

directly compared the accuracy of 3D measurements of LV volumes and ejection fraction (EF) have demonstrated the superiority of the 3D approach over the 2D methodology, which was shown to consistently underestimate LV volumes. This superiority has been demonstrated in both accuracy and reproducibility when compared with magnetic resonance imaging. With the introduction of matrix-array technology, quantification of LV volumes and EF can now be performed using software capable of automated frame-by-frame detection of the endocardial surface from the RT-3DE datasets. Currently, there is sufficient evidence in the medical literature to support the notion that RT-3DE determination of LV volumes, EF, and mass should be considered the method of choice in routine practice (2). This approach should be embraced to rapidly become part of the clinical mainstream, because many clinical decisions that affect patient care, including the indications for defibrillators and biventricular pacing, rely on accurate measurements of LV volumes and EF.

The utility of RT-3DE in evaluation of mitral stenosis and the accuracy of mitral valve orifice area measurements have been clearly established by multiple studies. The main advantage of RT-3DE imaging in this context is its ability to achieve a perpendicular en-face cut-plane of the mitral valve orifice, enabling accurate measurements of its area. When compared with traditional 2D and Doppler measurements, the RT-3DE approach best agreed with mitral orifice area calculations derived using the Gorlin formula, with the additional advantage of having lower intraobserver and interobserver variability (3). The ease of acquisition and on-line review of RT-

3DE images facilitates immediate assessment of the mitral valve commissural splitting, stretching, or tearing after percutaneous balloon mitral valvuloplasty.

Until just 1 year ago, 3D transesophageal echocardiography (TEE) was performed using a multiplane rotational approach for sequential data acquisition, gated to electrocardiography and respiration. This technique was limited by the need for multiple image sampling, resulting in lengthy data acquisition, and was frequently affected by radial artifacts. As a consequence of these limitations, 3D reconstruction TEE had not become part of the clinical routine and was used predominantly for research purposes. To overcome these limitations, a matrix-array TEE transducer was developed that combines novel electric circuitry with miniaturized beam-forming technology that accommodates thousands of fully sampled elements into the tip of an otherwise conventional TEE probe. Due to the exceptional quality and unique real-time 3D display of the mitral valve apparatus, this modality is poised to become the method of choice for preoperative planning of mitral valve surgery (4). The significant improvement in 3D image quality with the matrix-array TEE probe has also enabled parallel development of 3D volumetric quantification techniques of the mitral valve apparatus, which enhance our objective understanding of which patients should be referred for mitral valve repair due to complex degenerative mitral valve disease. The volumetric software for analysis of mitral and aortic valve geometry will also allow the performance of virtual operations and better understanding of the pathophysiology of mitral-aortic coupling. Since the matrix-array TEE probe also allows optimal visualization

of other cardiac structures with an exquisite level of detail, including bio-prosthetic and mechanical valves, mitral rings, the interatrial septum, pulmonary veins, and left atrial appendage (4,5), this technique is gradually becoming the modality of choice

portant that 3D datasets be incorporated into digital information systems with full rendering and quantification capabilities. Since RT-3DE has been adopted by all major manufacturers of cardiac ultrasound imaging equipment, it is of vital importance that investiga-

tricular volumes and function, which is important due to the increasing number of clinical decisions that depend on assessment of LV size and function. Three-dimensional echocardiographic imaging is uniquely well suited for investigations of cardiovascular pathophysiology that benefit from a 3D quantitative approach, particularly complex valvular heart disease like mitral stenosis and ischemic mitral regurgitation. Advances in transducer technology and processing now allow real-time acquisition and display of 3D volumetric datasets, and this imaging equipment is available at many clinical sites. Although this technology seems poised for a transition similar to the dramatic change that occurred when 2D imaging supplanted M-mode, it has yet to be incorporated into the standard examination in the majority of laboratories. Given these recent technical improvements and data to support its use as a standard part of the echocardiogram, what factors have prevented its adoption as a routine technique today?

Spatial and temporal limitations. The most basic challenge relates to the visual display of the 3D data: how do we view and interpret these images? Displays using automated shadowing and wire-frame models have enhanced the perception of 3D images displayed on a 2D monitor, but much of the information is still best appreciated on 2D image displays, particularly when orthogonal 2D images are displayed simultaneously. Artifacts are common, so interpreters often rely on cropped 2D images for qualitative interpretations, but 2D images derived from volumetric data may appear less clear than standard 2D images. Users must choose between full-volume datasets that require breath-holding and multiple cardiac cycles or less-than-full-volume views that can reduce the impact of heart rate variability and motion artifact, although this limitation is soon likely to disappear. Frame rates of ap-

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for the guidance of percutaneous interventions, such as mitral balloon valvuloplasty, closure of atrial septal defects, left atrial appendages, and perivalvular leaks.

Although both transthoracic and transesophageal RT-3DE imaging are ready for prime time use because of their proven ability to improve the diagnostic accuracy of echocardiography in multiple clinical scenarios, further refinements are necessary to make this methodology even more robust and user-friendly. Thus, improvements in transducer and computer technology are required, including the capability of wider angle acquisitions, with and without color flow imaging, to be completed in a single cardiac cycle. This will shorten the data acquisition and eliminate stitching artifacts. Versatile multi-tasking transducers with 2D, 3D, color, and tissue Doppler capabilities with smaller footprint and weight and higher spatial and temporal resolution must be developed to significantly reduce the time needed to complete an examination. It is anticipated that quantification of all cardiac chambers, including flow dynamics, will be performed on the imaging system, eliminating the need for off-line analysis. This is of particular importance in the interventional settings and operating room, where immediate quantitative feedback is important. For the purposes of storage and retrieval for easy interpretation, it is im-

tors agree upon uniform strategies for image acquisition, quantification, and display.

In summary, there currently is sufficient evidence that transthoracic RT-3DE imaging is superior to traditional 2D echocardiography and should be routinely used in 2 clinical scenarios: quantification of LV volume and EF and quantification of the mitral valve area in mitral stenosis. Future clinical applications of this technology are also likely to include stress testing, with real-time volumetric or simultaneous multiplane imaging from a single transducer position. The optimal visualization of cardiac structures, including the mitral valve with the matrix TEE probe, will revolutionize pre-surgical planning of the mitral valve and improve the guidance of percutaneous intracardiac procedures.

3D Echocardiography Is (Almost) Ready for Routine Clinical Use

John M. Dent, MD, FACC

THE PACE OF TECHNICAL IMPROVEMENTS IN 3D ECHOCARDIOGRAPHIC IMAGING HAS ACCELERATED over the past decade. Numerous studies have demonstrated that adding 3D imaging to standard 2D increases the accuracy of quantitation of left ven-

proximately 25 Hz remain a limitation for tachycardic patients at rest or during stress.

Image acquisition, processing, and storage limitations. A complete 3D protocol involving acquisition of volumetric data from 4 transducer positions should add only a few minutes to a standard 2D echocardiogram (6). If all of the images needed to perform a complete study could be obtained or derived from this protocol, reducing or eliminating the need for acquisition of multiple 2D images and Doppler, then the time required to perform an echocardiogram would be significantly reduced, but overall image quality must not be compromised. Until the 3D volumetric data can be relied upon for complete image interpretation, however, this means that both equipment and acquisition costs will exceed the cost of a standard 2D echocardiogram.

The lack of an approved Digital Imaging and Communication in Medicine (DICOM) standard for 3D images has slowed the uniform transmission and storage of these digital images. Proprietary standards requiring the use of matched stand-alone workstations limit some research applications and create significant work flow barriers for the storage and retrieval of true 3D data; since echocardiograms are stored for documentation and to allow future comparisons, digital laboratories are now potentially encumbered by parallel storage systems and complicating image access, creating an additional burden for data back-up.

Cost-value issues. Although 3D echocardiography clearly enhances quantitation of chamber size and function, it is difficult to perform quantitative research involving qualitative changes in image interpretation. For this reason, along with general difficulties encountered when try-

ing echocardiogram, particularly given the established clinical value of accurate quantitation of left ventricular size and function. As the technology continues to improve, echocardiography laboratory workflow will need to be changed, or 3D echocardiography will remain an occa-

Demonstrating the incremental value added by 3D imaging will be very important.

ing to demonstrate improved patient outcomes directly related to cardiovascular imaging, there is a paucity of information supporting the additive value of 3D imaging compared with standard 2D imaging for qualitative improvement in image interpretation.

If 3D image acquisition can be shown to reduce the time required to perform a complete study, without reducing the quality of images obtained, then it will be possible to prove the additive value of this modality beyond the obvious quantitative improvements. Although such a transition will likely require a major re-engineering of workflow in laboratories, the resulting cost savings should not only cover the additional cost of 3D equipment but could also lead to a reduction in the overall technical cost of performing echocardiograms, which is of particular interest as we seek to contain a rapidly increasing national imaging budget.

Conclusions. There are enough current data to support the use of 3D echocardiography as a standard part of the adult

sionally used imaging modality. Demonstrating the incremental value added by 3D imaging will be very important (7). Assuming these steps are taken, it is easy to imagine an echocardiographic acquisition protocol of the future, which will consist of derivation of high quality images and accurate quantitative data entirely from a small number of rapidly obtained 3D volumetric datasets, but until this scenario is realized, echocardiographers will likely continue to rely more on standard 2D information than on that obtained from 3D.

Author Disclosures

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