Review of novel clinical applications of advanced, real-time, 3-dimensional echocardiography

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Advances in computer processing speed and memory along with the advent of the microbeam former that can sample an entire crystal of the ultrasound transducer made possible the performance of 3-dimensional echocardiography in real time (RT3DE). The miniaturization of a 3-dimensional transducer permitting its extension to transesophageal mode rapidly expanded its use in a variety of conditions. Recent development of user-friendly automated/semiautomated cropping and display software may make it rather simple, even for the novice to gather useful information from RT3DE. We discuss the background, technique, and cutting-edge research and novel clinical applications of advanced RT3DE, including left ventricular dyssynchrony assessment, 3-D speckle tracking, myocardial contrast echocardiography, complete 4-dimensional (4-D) shape and motion analysis of the left ventricle, 4-D volumetric analysis of the right ventricle, 3-D volume rendering of the mitral valve, and other percutaneous and surgical procedural applications. (Translational Research 2012;159:149–164)

Abbreviations: 2-D = 2-dimensional; 3-D = 3-dimensional; 4-D = 4-dimensional; 2DE = 2-dimensional echocardiography; CMR = cardiac magnetic resonance imaging; CRT = cardiac resynchronization therapy; DCM = dilated cardiomyopathy; LAA = left atrial appendage; LV = left ventricle; MV = mitral valve; RT3DE = real-time, 3-dimensional echocardiography; RV = right ventricle; RVOT = right ventricle outflow tract; SDI = systolic dyssynchrony index; STE = speckle tracking echocardiography; TEE = transesophageal echocardiogram; VSD = ventricular septal defect

The new era of translational medicine places greater demands on the diagnostic armamentarium than ever before. The novel paradigms in translational clinical research require greater quantitative precision than may be required in routine clinical practice. These growing demands created the need and niche for an inexpensive, safe, and versatile yet comprehensive volumetric depiction of the heart in 3 geometrical dimensions and in a fourth dimension: time.

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Four-dimensional (4-D) echocardiography is made possible by the most recent version of real-time, 3-dimensional echocardiography (RT3DE) that is now feasible from both transthoracic and transesophageal approaches. This has been accomplished by recent advances in computer processing speed and memory, along with miniaturization of beam-formation hardware. The microbeam former has capabilities to sample the entire crystal of the transducer head, converting a sparse array to a dense array transducer making beam steering powerful with abilities to generate a pyramidal burst of ultrasound, resulting in a high-resolution, RT3D-rendered data set. Various vendors offer newer generation RT3DE transducers that can provide nongated data sets, which can be acquired in a single heartbeat or gated ones acquired over several heart beats with better temporal resolution. Most new transducers have M-mode, B-mode, X-plane imaging, color, and spectral Doppler as well as harmonic generation. They also conveniently display, after volume rendering, 2 to 3

Table I. Common 3-D acquisition modes: features and applications*

	Wide-angle/ full-volume acquisition	Color Doppler acquisition	Real-time display/ acquisition	Zoom mode display/ acquisition
Real time	No	No	Yes	Yes
Acquisition time	4–7 cardiac cycles 1 cardiac cycle with limited spatial or temporal resolution	Usually 4–14 cardiac cycles 1 cardiac cycle but limited width and elevation of the data set	1 cardiac cycle	Usually 1, can be up to 6 cardiac cycles if the sector is wide
Temporal resolution	Up to 50 Hz	up to 20 Hz	Up to 30 Hz	Up to 10 Hz
Applications	Volumetric analysis of various chambers, stress and perfusion echocardiography, 4DE (dyssynchrony/ deformation imaging) ASD, VSD, thrombi, tumors, pericardial pathology, mitral and tricuspid valve pathology, congenital heart disease	Valvular/paravalvular regurgitation, ASD, VSD, abscess, fistulae	Guidance of interventional and electrophysiologic procedures	Valvular pathology, vegetations, LAA,

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orthogonal 2-dimensional (2-D) imaging planes if chosen besides several transverse planes.

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Constraints imposed by the laws of ultrasound physics inherent in 2-D image acquisition, such as optimization of color and time gain, also apply to RT3DE. Given the increased magnitude of information the system has to process, both the spatial resolution and frame rate generated by the RT3DE are low compared with 2-dimensional echocardiography (2DE). It is crucial to keep the depth and sector width of the image to the least necessary to obtain better spatial resolution and higher frame rates in an acquired 3-D data set. In addition, certain advanced systems permit the reduction in line density to permit higher frame rates as well. However, the spatial resolution is usually largely fixed and is dependent on the aperture size and the center frequency of the transducer, which is determined by the vendor. Most contemporary models provide an axial resolution of 0.4 to 0.6 mm and a lateral and elevation resolution of 2 to 4 mm at a depth of 10 to 12 cm. The full volume/wide angle display with and without color is used commonly to acquire full volume/wide angled volumetric and color data sets, respectively. The real-time narrow angle display is used while guiding procedures in real time, and the zoom mode is used to focus on smaller structures. Tables I and II summarize the salient features and applications of the common 3-D acquisition modes and the common pathways used to perform 3DE.[1]

Electrocardiography gated, stitched 3-D volumes with and without color Doppler acquired within a single breath hold provide better spatial resolution but require patient cooperation. In contrast, the nonstitched data sets are obtained instantaneously in a single heart beat eliminating the stitch artifacts in space and time but yield lower spatial or temporal resolution. Image processing is performed by image cropping, volumetric analysis, or segmentation, as well as 4-dimensional (4-D) analyses such as dyssynchrony or deformation imaging.

Cropping is the virtual sectioning of a 3-D data set to view structures within, from any desired vantage point. It can be performed in any of the 3 predetermined cropping planes (x, y, and z) or in a manually adjustable, single-slice plane. To help standardize RT3D transesophageal echocardiogram (TEE), the acquisition of a full-volume data set from bicommissural midesophageal view aligning the x-axis along the mitral commissure, y-axis along an imaginary line between LV apex and the center of the mitral annulus, and z-axis along the anteroposterior mitral annulus has been recommended. Cropping of this data set in certain recommended planes were proposed to provide not only the *en face* views of structures of interest but also those analogous to standard 2D TEE, permitting rapid online analysis.[2] However, this finding has not been validated in a clinical setting.

A volumetric analysis can be performed manually or semiautomatically using segmentation techniques. Integration of this information over time enables dyssynchrony imaging. Some of the commercial systems also provide epicardial and endocardial speckle/wall motion